International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R P.1853-1

(02/2012)

Tropospheric attenuation time series synthesis

P Series

Radiowave propagation

International Telecommunication Union

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SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
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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 P.1853-1

Tropospheric attenuation time series synthesis

(2009-2011)

Scope

This Recommendation provides methods to synthesize rain attenuation and scintillation for terrestrial and Earth-space paths and total attenuation and tropospheric scintillation for Earth-space paths.

The ITU Radiocommunication Assembly,

considering

a) that for the proper planning of terrestrial and Earth-space systems it is necessary to have appropriate methods to simulate the time dynamics of the propagation channel;

b) that methods have been developed to simulate the time dynamics of the propagation channel with sufficient accuracy,

recommends

1 that the method given in Annex 1 should be used to synthesize the time series of rain attenuation for terrestrial or Earth-space paths;

2 that the method given in Annex 1 should be used to synthesize the time series of scintillation for terrestrial or Earth-space paths;

3 that the method given in Annex 1 should be used to synthesize the time series of total tropospheric attenuation and tropospheric scintillation for Earth-space paths.

Annex 1

1 Introduction

The planning and design of terrestrial and Earth-space radiocommunication systems requires the ability to synthesize the time dynamics of the propagation channel. For example, this information may be required to design various fade mitigation techniques such as, *inter alia*, adaptive coding and modulation, and transmit power control.

The methodology presented in this Annex provides a technique to synthesize rain attenuation and scintillation time series for terrestrial and Earth-space paths and total attenuation and tropospheric scintillation for Earth-space paths that approximate the rain attenuation statistics at a particular location.

2 Rain attenuation time series synthesis method

2.1 Overview

The time series synthesis method assumes that the long-term statistics of rain attenuation is a log-normal distribution. While the ITU-R rain attenuation prediction methods in Recommendation ITU-R P.530 for terrestrial paths and Recommendation ITU-R P.618 for Earth-space paths are not exactly log-normal, these rain attenuation distributions are well-approximated by a log-normal distribution over the most significant range of exceedance probabilities. The terrestrial and Earth-space rain attenuation prediction methods predict non-zero rain attenuation for exceedance probabilities greater than the probability of rain; however, the time series synthesis method adjusts the attenuation time series so the rain attenuation corresponding to exceedance probabilities greater than the probability of rain is 0 dB.

For terrestrial paths, the time series synthesis method is valid for frequencies between 4 GHz and 40 GHz and path lengths between 2 km and 60 km.

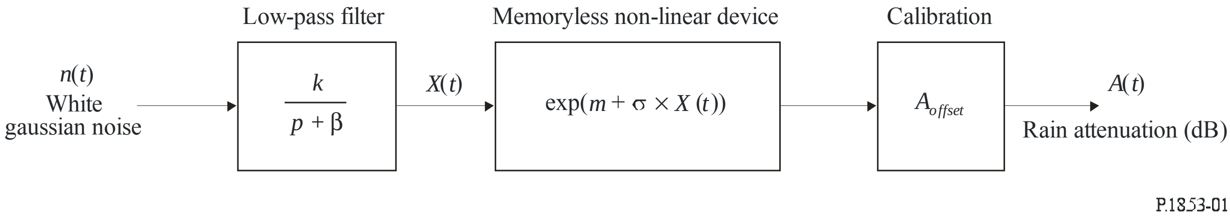
For Earth-space paths, the time series synthesis method is valid for frequencies between 4 GHz and 55 GHz and elevation angles between 5º and 90º.

The time series synthesis method generates a time series that reproduces the spectral characteristics, fade slope and fade duration statistics of rain attenuation events. Interfade duration statistics are also reproduced but only within individual attenuation events.

As shown in Fig. 1, the rain attenuation time series, $A(t)$, is synthesized from the discrete white Gaussian noise process, $n(t)$. The white Gaussian noise is low-pass filtered, transformed from a normal distribution to a log-normal distribution in a memoryless non-linearity, and calibrated to match the desired rain attenuation statistics.

FIGURE 1

Block diagram of the rain attenuation time series synthesizer



The time series synthesizer is defined by five parameters:

- m: mean of the log-normal rain attenuation distribution
- σ: standard deviation of the log-normal rain attenuation distribution
- p: probability of rain
- β: parameter that describes the time dynamics (s^{-1})
- A_{offset}: offset that adjusts the time series to match the probability of rain (dB)

2.2 Step-by-step method

The following step-by-step method is used to synthesize the attenuation time series $A_{rain}(kT_s)$, $k = 1, 2, 3, ...$, where T_s is the time interval between samples, and k is the index of each sample.

A Estimation of m and σ

The parameters m and σ are determined from the cumulative distribution of rain attenuation vs. probability of occurrence. Rain attenuation statistics can be determined from local measured data, or, in the absence of measured data, the rain attenuation prediction methods in Recommendation ITU-R P.530 for terrestrial paths and Recommendation ITU-R P.618 for Earth-space paths can be used.

For the path and frequency of interest, perform a log-normal fit of rain attenuation vs. probability of occurrence as follows:

Step A1: Determine P^{rain} (% of time), the probability of rain on the path. P^{rain} can be well approximated as $P_0(Lat,Lon)$ derived in Recommendation ITU-R P.837.

Step A2: Construct the set of pairs $[P_i, A_i]$ where P_i (% of time) is the probability the attenuation A_i(dB) is exceeded where $P_i \leq P^{rain}$. The specific values of P_i should consider the probability range of interest; however, a suggested set of time percentages is 0.01, 0.02, 0.03, 0.05, 0.1, 0.2, 0.3, 0.5, 1, 2, 3, 5, and 10%, with the constraint that $P_i \leq P^{rain}$.

Step A3: Transform the set of pairs $[P_i, A_i]$ to $\left[Q^{-1}\left(\frac{P_i}{100}\right), \ln A_i \right]$,

where:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{t^2}{2}} dt \qquad (1)$$

Step A4: Determine the variables $m_{\ln A_i}$ and $\sigma_{\ln A_i}$ by performing a least-squares fit to $\ln A_i = \sigma_{\ln A_i} \; Q^{-1}\left(\frac{P_i}{100}\right) + m_{\ln A_i}$ for all i. The least-squares fit can be determined using the "Step-by-step procedure to approximate a complementary cumulative distribution by a log-normal complementary cumulative distribution" described in Recommendation ITU-R P.1057.

B Low-pass filter parameter

Step B1: The parameter $\beta = 2 \times 10^{-4}$ (s^{-1}).

C Attenuation offset

Step C1: The attenuation offset, A_{offset} (dB), is computed as:

$$A_{offset} = e^{m + \sigma Q^{-1}\left(\frac{P^{rain}}{100}\right)} \qquad (2)$$

D Time series synthesis

The time series, $A_{rain}(kT_s)$, $k = 1, 2, 3, ...$ is synthesized as follows:

Step D1: Synthesize a white Gaussian noise time series, $n(kT_s)$, where $k = 1, 2, 3, ...$ with zero mean and unit variance at a sampling period, T_s, of 1 s.

Step D2: Set $X(0) = 0$

Step D3: Filter the noise time series, $n(kT_s)$, with a recursive low-pass filter defined by:

$$X(kT_s) = \rho \times X((k-1)T_s) + \sqrt{1-\rho^2} \times n(kT_s) \qquad \text{for } k = 1, 2, 3, ... \qquad (3)$$

where:

$$\rho = e^{-\beta T_s} \tag{4}$$

Step D4: Compute $Y_{rain}(kT_s)$, for k = 1, 2, 3, ... as follows:

$$Y_{rain}(kT_s) = e^{m + \sigma X(kT_s)} \tag{5}$$

Step D5: Compute $A_{rain}(kT_s)$ (dB), for k = 1, 2, 3, ... as follows:

$$A_{rain}(kT_s) = \text{Maximum}\left[Y(kT_s) - A_{offset}, 0\right] \tag{6}$$

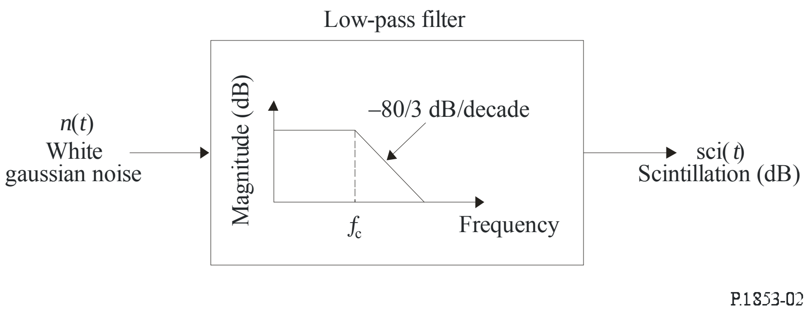
Step D6: Discard the first 200 000 samples from the synthesized time series (corresponding to the filter transient). Rain attenuation events are represented by sequences whose values are above 0 dB for a consecutive number of samples.

3 Scintillation time series synthesis method

As shown in Fig. 2, a scintillation time series, $sci(t)$, can be generated by filtering white Gaussian noise, $n(t)$, such that the asymptotic power spectrum of the filtered time series has an $f^{-8/3}$ roll-off and a cut-off frequency, f_c, of 0.1 Hz. Note that the standard deviation of the scintillation increases as the rain attenuation increases.

FIGURE 2

Block diagram of the scintillation time series synthesizer



4 Integrated cloud liquid water content time series synthesis method

4.1 Overview

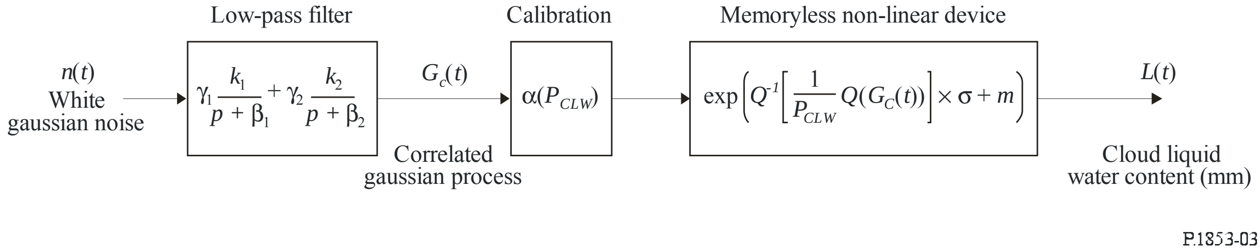
As it is suggested in Recommendation ITU-R P.840, the time series synthesis method approximates the statistics of the long-term integrated liquid water content (ILWC) by a log-normal distribution.

The time series synthesis method generates a time series that reproduces the spectral characteristics, rate of change and duration statistics of cloud liquid content events.

As shown in Fig. 3, the liquid content time series, $L(t)$, is synthesized from the discrete white Gaussian noise process, $n(t)$. The white Gaussian noise is low-pass filtered, truncated to match the desired cloud probability of occurrence, and transformed from a truncated normal distribution to a conditioned log-normal distribution in a memoryless non-linearity.

FIGURE 3

Block diagram of the cloud ILWC time series synthesizer



The time series synthesizer is defined by eight parameters:

- m: mean of the log-normal rain attenuation distribution
- σ: standard deviation of the log-normal rain attenuation distribution
- P_{CLW}: probability of clouds
- α: truncation threshold of the correlated Gaussian noise
- β_1: parameter that describes the time dynamics of the process fast component (s^{-1})
- β_2: parameter that describes the time dynamics of the process slow component (s^{-1})
- γ_1: parameter that describes the weight of the process fast component
- γ_2: parameter that describes the weight of the process slow component

4.2 Step-by-step method

The following step-by-step method is used to synthesize the cloud liquid water content time series $L(kT_s)$, $k = 1, 2, 3, ...$, where T_s is the time interval between samples, and k is the index of each sample.

A Estimation of m, σ and P_{CLW}

The mean, m, standard deviation, σ, and probability of liquid water, P_{CLW}, parameters of the log-normal distribution are available in the form of maps from Recommendation ITU-R P.840.

For the location of interest, determine the conditional log-normal parameters as follows:

Step A1: Determine the parameters, $m_1, m_2, m_3, m_4, \sigma_1, \sigma_2, \sigma_3, \sigma_4, P_{CLW1}, P_{CLW2}, P_{CLW3}$ and P_{CLW4} at the four closest grid points of the digital maps provided in Recommendation ITU-R P.840.

Step A2: determine the m, σ and P_{CLW} parameters value at the desired location by performing a bi-linear interpolation of the four values of each parameter at the four grid points as described in Recommendation ITU-R P.1144.

B Low-pass filter parameters

Step B1: The parameter $\beta_1 = 7.17 \times 10^{-4}$ (s^{-1}).

Step B2: The parameter $\beta_2 = 2.01 \times 10^{-5}$ (s^{-1}).

Step B3: The parameter $\gamma_1 = 0.349$.

Step B4: The parameter $\gamma_2 = 0.830$.

C Truncation threshold

Step C1: The truncation threshold α is computed as:

$$\alpha = Q^{-1}(P_{CLW}) \qquad (7)$$

where the Q function is defined in § 2.2.A and documented in Recommendation ITU-R P.1057.

D Time series synthesis

The time series, $L(kT_s)$, $k = 1, 2, 3, \ldots$ is synthesized as follows:

Step D1: Synthesize a white Gaussian noise time series, $n(kT_s)$, where $k = 1, 2, 3, \ldots$ with zero mean and unit variance at a sampling period, T_s, of 1 s.

Step D2: Set $X_1(0) = 0$; $X_2(0) = 0$

Step D3: Filter the noise time series, $n(kT_s)$, with two recursive low-pass filters defined by:

$$\begin{cases} X_1(kT_s) = \rho_1 \times X_1((k-1)T_s) + \sqrt{1-\rho_1^2} \times n(kT_s) \\ X_2(kT_s) = \rho_2 \times X_2((k-1)T_s) + \sqrt{1-\rho_2^2} \times n(kT_s) \end{cases} \quad \text{for } k = 1, 2, 3, \ldots. \qquad (8)$$

where:

$$\begin{cases} \rho_1 = e^{-\beta_1 T_s} \\ \rho_2 = e^{-\beta_2 T_s} \end{cases} \qquad (9)$$

Step D4: Compute $G_c(kT_s)$, for $k = 1, 2, 3, \ldots$ as follows:

$$G_C(kT_s) = \gamma_1 \times X_1(kT_s) + \gamma_2 \times X_2(kT_s) \qquad (10)$$

Step D5: Compute $L(kT_s)$ (dB), for $k = 1, 2, 3, \ldots$ as follows:

$$L(kT_s) = \begin{cases} \exp\left(Q^{-1}\left[\frac{1}{P_{CLW}} Q(G_C(kT_s)) \right] \times \sigma + m \right) & \text{for} \quad G_C(kT_s) > \alpha \\ 0 & \text{for} \quad G_C(kT_s) \le \alpha \end{cases} \qquad (11)$$

Step D6: Discard the first 500 000 samples from the synthesized time series (corresponding to the filter transient). Cloud events are represented by sequences whose values are above 0 mm for a consecutive number of samples.

5 Integrated water vapour content time series synthesis method

5.1 Overview

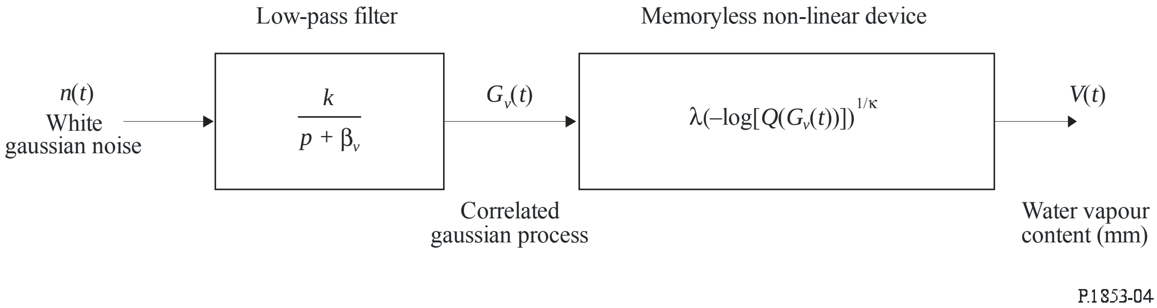
The time series synthesis method assumes that the long-term statistics of integrated water vapour content (IWVC) is a Weibull distribution. While the ITU-R IWVC distributions predicted in Recommendation ITU-R P.836 are not exactly Weibull, these IWVC distributions are well-approximated by a Weibull distribution over the most significant range of exceedance probabilities.

The time series synthesis method generates a time series that reproduces the spectral characteristics and the distribution of water vapour content.

As shown in Fig. 4, the water vapour content time series, $V(t)$, is synthesized from the discrete white Gaussian noise process, $n(t)$. The white Gaussian noise is low-pass filtered and transformed from a normal distribution to a Weibull distribution in a memoryless non-linearity.

FIGURE 4

Block diagram of the integrated water vapour content time series synthesizer



The time series synthesizer is defined by three parameters:

- κ: parameter of the Weibull IWVC distribution
- λ: parameter of the Weibull IWVC distribution
- β_V: parameter that describes the time dynamics (s^{-1})

5.2 Step-by-step method

The following step-by-step method is used to synthesize the IWVC time series $V(kT_s)$, $k = 1, 2, 3, ...$, where T_s is the time interval between samples, and k is the index of each sample.

A Estimation of κ *and* λ

The parameters κ and λ are determined from the cumulative distribution of IWVC vs. probability of occurrence. IWVC statistics can be determined from local measured data, or, in the absence of measured data, the IWVC prediction methods in Recommendation ITU-R P.836 can be used.

For the location of interest, perform a Weibull fit of IWVC vs. probability of occurrence as follows:

Step A1: Construct the set of pairs [P_i, V_i] where P_i (% of time) is the probability the IWVC V_i(mm) is exceeded. The specific values of P_i should consider the probability range of interest; however, a suggested set of time percentages is 0.1, 0.2, 0.3, 0.5, 1, 2, 3, 5, 10, 20, 30 and 50%.

Step A2: Transform the set of pairs [P_i, V_i] to $\left[\ln(-\ln P_i), \ln V_i\right]$.

Step A3: Determine the intermediate variables a and b by performing a least squares fit to the linear function:

$$\ln(-\ln P_i) = a \ln V_i + b \tag{12}$$

as follows:

$$\begin{cases} a = \dfrac{n\sum\limits_{i=1}^{n}\ln V_i \ln(-\ln P_i) - \sum\limits_{i=1}^{n}\ln V_i \sum\limits_{i=1}^{n}\ln(-\ln P_i)}{n\sum\limits_{i=1}^{n}[\ln V_i]^2 - \left[\sum\limits_{i=1}^{n}\ln V_i\right]^2} \\ b = \dfrac{\sum\limits_{i=1}^{n}\ln(-\ln P_i) - a\sum\limits_{i=1}^{n}\ln V_i}{n} \end{cases} \tag{13}$$

Step A4: Determine parameters κ and λ as follows:

$$\begin{cases} \kappa = a \\ \lambda = \exp\left(-\dfrac{b}{a}\right) \end{cases} \tag{14}$$

B Low-pass filter parameter

Step B1: The parameter $\beta_V = 3.24 \times 10^{-6}$ (s^{-1}).

C Time series synthesis

The time series, $V(kT_s)$, k = 1, 2, 3, ... is synthesized as follows:

Step C1: Synthesize a white Gaussian noise time series, $n(kT_s)$, where k = 1, 2, 3, ... with zero mean and unit variance at a sampling period, T_s, of 1 s.

Step C2: Set $G_V(0) = 0$

Step C3: Filter the noise time series, $n(kT_s)$, with a recursive low-pass filter defined by:

$$G_V(kT_s) = \rho \times G_V((k-1)T_s) + \sqrt{1-\rho^2} \times n(kT_s) \qquad \text{for } k = 1, 2, 3, ... \tag{15}$$

where:

$$\rho = e^{-\beta_V T_s} \tag{16}$$

Step C4: Compute $V(kT_s)$, for k = 1, 2, 3, ... as follows:

$$V(kT_s) = \lambda(-\log[Q(G_V(kT_s))])^{1/\kappa} \tag{17}$$

where the Q function is defined in § 2.2.A and documented in Recommendation ITU-R P.1057.

Step C5: Discard the first 5 000 000 samples from the synthesized time series (corresponding to the filter transient).

6 Total attenuation and scintillation time series synthesis method for Earth-space paths

6.1 Overview

Total attenuation and scintillation time series are generated using the scheme illustrated on Fig. 5 and making use of the methods described in the above sections. An appropriate correlation between clouds and rain has been introduced. This correlation coefficient together with the fact that the probability to have clouds on the link is higher than the probability to have rain guaranties that clouds are always generated during rain events.

Cloud liquid water content is interpolated if the two following criteria are simultaneously verified:

– a rain event is generated (synthetic rain attenuation is greater than 0 dB);

– ILWC exceeds the 1 mm threshold.

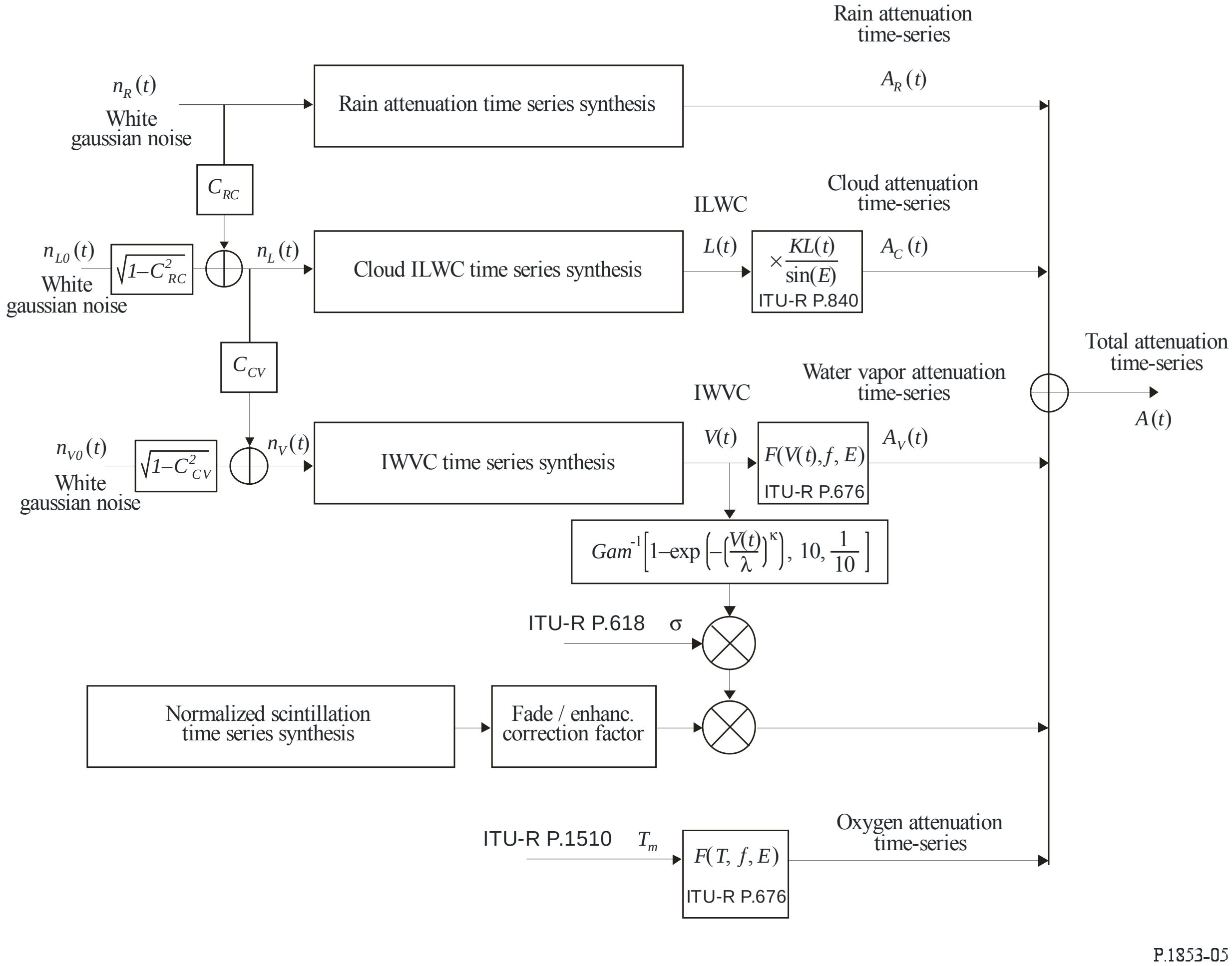
Due to the very low dynamic parameter value for the IWVC component, the first **5.10^6** samples have to be discarded from the synthesized time series for all the considered effects (corresponding to the IWVC filter transient).

For Earth-space paths, the time series synthesis method is valid for frequencies between 4 GHz and 55 GHz and elevation angles between 5º and 90º. For some circumstances (e.g. low frequencies, moderate to high elevations, temperate areas), the total attenuation may be approximated by the rain attenuation with sufficient accuracy.

The time series synthesis method generates a time series that reproduces the spectral characteristics, fade slope and fade duration statistics of total attenuation events. Interfade duration statistics are also reproduced but only within individual attenuation events.

FIGURE 5

Block diagram of the total attenuation and scintillation time series synthesizer



6.2 Step-by-step method

The following step-by-step method is used to synthesize the attenuation time series $A(kT_s)$, $k = 1, 2, 3, ...$, where T_s is the time interval between samples, and k is the index of each sample.

A Correlation coefficients

Step A1: The parameter $C_{RC} = 1$.

Step A2: The parameter $C_{CV} = 0.8$.

B Scintillation polynomials

Step B1: define the scintillation fading and enhancement polynomials as:

$$a_{Fade}(P) = -0.061\times(\log_{10}(P))^3 + 0.072\times(\log_{10}(P))^2 - 1.71\times\log_{10}(P) + 3.0$$
$$a_{Enhanc}(P) = -0.0597\times(\log_{10}(P))^3 - 0.0835\times(\log_{10}(P))^2 - 1.258\times\log_{10}(P) + 2.672 \quad (18)$$

C Time series synthesis

The time series, $A(kT_s)$, $k = 1, 2, 3, ...$ is synthesized as follows:

Step C1: Synthesize a white Gaussian noise time series, $n_R(kT_s)$, where $k = 1, 2, 3, ...$ with zero mean and unit variance at a sampling period, T_s, of 1 s.

Step C2: Synthesize a white Gaussian noise time series, $n_{L0}(kT_s)$, where $k = 1, 2, 3, ...$ with zero mean and unit variance at a sampling period, T_s, of 1 s.

Step C3: Synthesize a white Gaussian noise time series, $n_{V0}(kT_s)$, where $k = 1, 2, 3, ...$ with zero mean and unit variance at a sampling period, T_s, of 1 s.

Step C4: Synthesize a white Gaussian noise time series, $n_L(kT_s)$, where $k = 1, 2, 3, ...$ as follows:

$$n_L(kT_s) = C_{RC}\times n_R(kT_s) + \sqrt{1-C_{RC}^2}\times n_{L0}(kT_s) \quad (19)$$

Step C5: Synthesize a white Gaussian noise time series, $n_V(kT_s)$, where $k = 1, 2, 3, ...$ as follows:

$$n_V(kT_s) = C_{CV}\times n_L(kT_s) + \sqrt{1-C_{CV}^2}\times n_{V0}(kT_s) \quad (20)$$

Step C6: Compute the rain attenuation time series $A(kT_s)$ starting from the Gaussian noise time series, $n_R(kT_s)$, following the procedure recommended in § 2 of this Recommendation and replace *step D6* of § 2 by the following: discard the first 5 000 000 samples from the synthesized time series.

Step C7: Compute the cloud integrated liquid water content time series $L(kT_s)$ starting from the Gaussian noise time series, $n_L(kT_s)$, following the procedure recommended in § 4 of this Recommendation and replace *step D6* of § 4 by the following: discard the first 5 000 000 samples from the synthesized time series.

Step C8: Convert the cloud integrated liquid water content time series $L(kT_s)$ into cloud attenuation time series $A_C(kT_s)$ following the method recommended in Recommendation ITU-R P.840.

Step C9: Identify time stamps k_1T_s, k_2T_s, k_3T_s, … where the two following conditions are simultaneously verified:

$$1 - A_R(kT_s) > 0$$

$$2 - L(kT_s) > 1 \tag{21}$$

Step C10: Discard the computed values of $A_C(kT_s)$ corresponding to the time stamps k_1T_s, k_2T_s, k_3T_s, … identified at *Step C8* and compute instead $A_C(kT_s)$ for these time stamps based on a linear interpolation vs. time starting from the non-discarded cloud attenuations values.

Step C11: Compute the integrated water vapour content time series $V(kT_s)$ starting from the Gaussian noise time series, $n_V(kT_s)$, following the procedure recommended in § 5 of this Recommendation.

Step C12: Convert the integrated water vapour content time series $V(kT_s)$ into water vapour attenuation time series $A_V(kT_s)$ following the approximate estimation of slant path water vapour attenuation method recommended in Recommendation ITU-R P.676 (Annex 2 Section 2.3).

Step C13: Compute the mean annual temperature T_m for the location of interest using experimental values if available. Else, the method provided in Recommendation ITU-R P.1510 can be used to predict T_m.

Step C14: Convert the mean annual temperature T_m into mean annual oxygen attenuation A_O following the method recommended in Recommendation ITU-R P.676.

Step C15: Synthesize unit variance scintillation time series $Sci_0(kT_s)$ following the method recommended in § 3 of this Recommendation.

Step C16: Compute the correction coefficient time series $C_x(kT_s)$ in order to distinguish between scintillation fades and enhancements:

$$C_x(k.Ts) = \begin{cases} \dfrac{a_{Fade}\left(100 \times Q[Sci_0(K.Ts)]\right)}{a_{Enhanc}\left(100 \times Q[Sci_0(K.Ts)]\right)} & \text{for} \quad Sci_0(K.Ts) > 0 \\ 1 & \text{for} \quad Sci_0(K.Ts) \leq 0 \end{cases} \tag{22}$$

where the Q function is defined in § 2.2.A and documented in Recommendation ITU-R P.1057.

Step C17: Transform the integrated water vapour content time series $V(kT_s)$ into the Gamma distributed time series $Z(kT_s)$ as follows:

$$Z(k.Ts) = Gam^{-1}\left[1 - \exp\left(-\left(\frac{V(k.Ts)}{\lambda}\right)^{\kappa}\right), 10, \frac{1}{10}\right] \tag{23}$$

where κ and λ are the integrated water vapour content Weibull distribution parameters, and the function *Gam* is the Gamma complementary distribution function documented in Recommendation ITU-R P.1057 and defined as:

$$Gam(x, k, \vartheta) = \int_x^{\infty} \frac{x^{k-1}\exp(-x/\theta)}{\Gamma(k)\theta^k}\,dt \tag{24}$$

Step C18: Compute the scintillation standard deviation σ following the method recommended in Recommendation ITU-R P.618.

Step C19: Compute the scintillation time series $Sci(kT_s)$ as follows:

$$Sci(kT_s) = \begin{cases} \sigma \times Sci_0(kT_s) \times C_x(k.Ts) \times Z(kT_s) \times [A_R(kT_s)]^{\frac{5}{12}} & \text{for} \quad A_R(kT_s) > 1 \\ \sigma \times Sci_0(kT_s) \times C_x(k.Ts) \times Z(kT_s) & \text{for} \quad A_R(kT_s) \le 1 \end{cases} \tag{25}$$

Step C20: Compute total tropospheric attenuation time series $A(kT_s)$ as follows:

$$A(kT_s) = A_R(kT_s) + A_C(kT_s) + A_V(kT_s) + A_O + Sci(kT_s) \tag{26}$$

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