HOT-EOT Channel Modeling

March 6, 2025

Objective

- Ondas performed in 2024, NGHE tests on a live train in MxV facility in Pueblo, CO. The tests were done over the FAST loop and over the High Speed Loop (HSL). The maximum speed of the train was 40 miles/hour and the length of the train was 1.3 miles. The results of the HSL tests are summarized in Ondas NGHE Phase 2 Test Report v1.10.
- Ondas developed NGHE channel models for scenarios not tested at MxV. These scenarios include longer trains, higher speed and multipath due to reflections from multiple wayside objects. These channel models are shown in this presentation.
- Ondas employs a channel emulator to test its IEEE802.16t DPP based NGHE solution over an emulated NGHE channel.

Parameters Used

- Channel type – Rayleigh Typical Urban Case (with 3 multipath)
  - Maximum Average power variation for multipaths is 22 dB.
  - Maximum path delay 1.4 μs.
- Doppler cases – 10 mph, 30 mph, 50 mph, 70 mph
- RF Frequency – 450 MHz.

Channel Modelling

Since we assume there is no LoS path, the Rayleigh multipath fading channel simulators in Communications Toolbox is used which is band-limited discrete multipath channel model. This implementation assumes that the delay power profile and the Doppler spectrum of the channel are separable. The multipath fading channel is therefore modeled as a linear finite impulse-response (FIR) filter. Let $\{s_i\}$ denote the set of samples at the input to the channel. Then the samples $\{y_i\}$ at the output of the channel are related to $\{s_i\}$ through:

$$y_i = \sum_{n=-N_1}^{N_2} s_i - n g_n$$

where $\{g_n\}$ is the set of tap weights given by:

$$g_n = \sum_{k=1}^{K} a_k sinc\left[\frac{\tau_k}{T_s} - n\right], -N_1 \leq \mathrm{n} \leq N_2$$

Channel Modelling

In the previous equations:

- Ts is the input sample period to the channel.
- $\{\tau_k\}$, where $1 \leq k \leq K$, is the set of path delays. K is the total number of paths in the multipath fading channel.
- $\{a_k\}$, where $1 \leq k \leq K$, is the set of complex path gains of the multipath fading channel. These path gains are uncorrelated with each other.
- Each multipath in this model is modeled using some number of sinusoids. N_1 and N_2 represent those numbers which are chosen so that $|g_n|$ is small when n is less than $-N_1$ or greater than N_2.
- Two techniques, filtered Gaussian noise and sum-of-sinusoids, are used to generate the set of complex path gains, a_k.

Channel Modelling

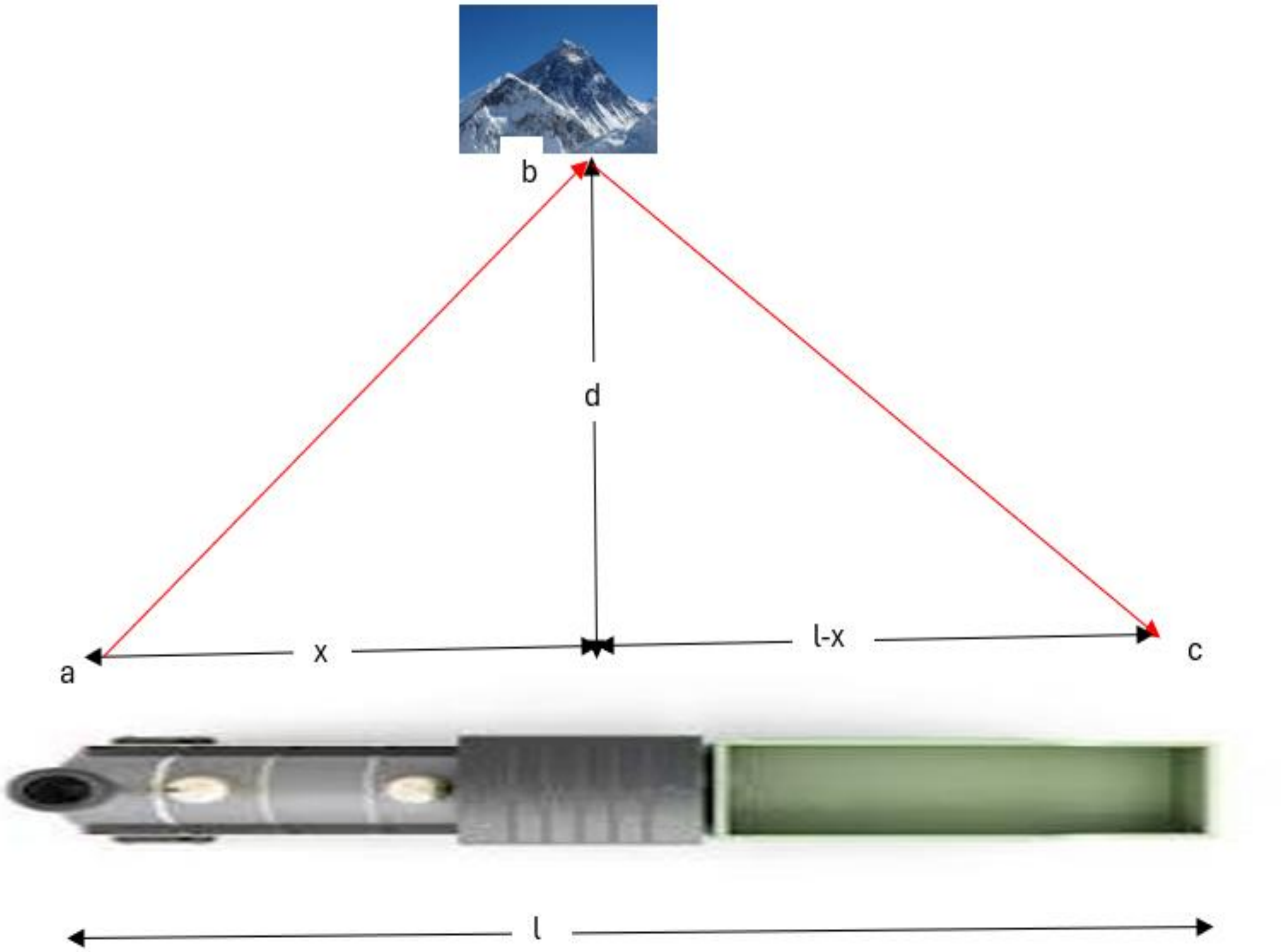
Filtered Gaussian Noise Technique

- A complex uncorrelated (white) Gaussian process with zero mean and unit variance is generated in discrete time.
- The complex Gaussian process is filtered by a Doppler filter with frequency response $H(f)=\sqrt{S(f)}$, where $S(f)$ denotes the desired Doppler power spectrum. By default, the Doppler power spectrum is Jakes' spectrum whose power spectral formula is shown in [1].
- The filtered complex Gaussian process is interpolated so that its sample period is consistent with the sample period of the input signal. A combination of linear and polyphase interpolation is used.

[1] https://onlinelibrary.wiley.com/doi/pdf/10.1002/0470847808.app1

Multipath Estimation

Let l be the length of the train and d be the perpendicular distance of the mountain from the train.



Total length of the multipath,

$$D = ab + bc$$

$$D = \sqrt{4d^2 + l^2}$$

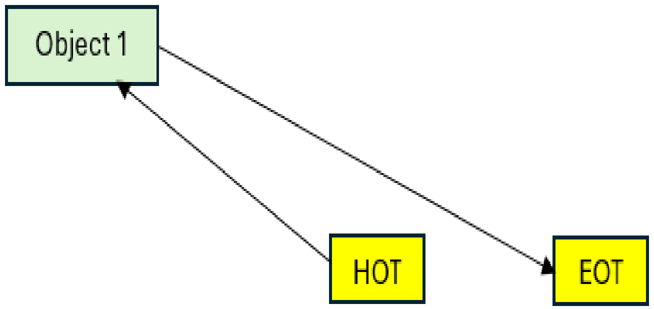
Path-delay is then given by,

$$\tau = \frac{D - l}{c},$$

$$where\ c = speed\ of\ light$$

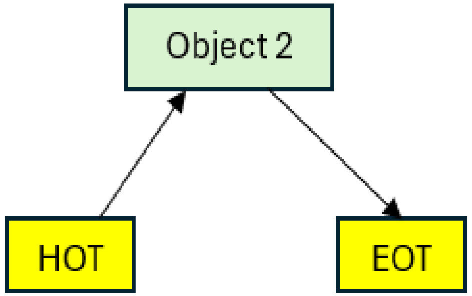
Doppler Estimation

Scenario 1



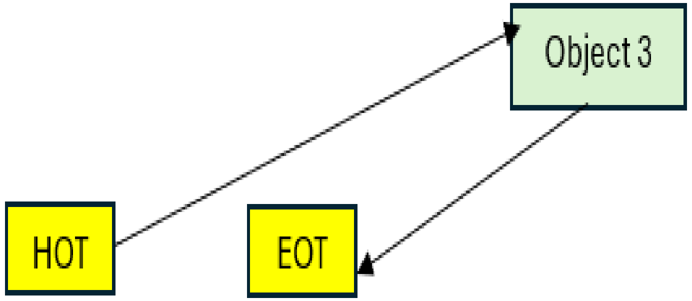
$$f_o = f_s$$

Scenario 2



$$f_o = \frac{v + v_s}{v - v_s} f_s$$

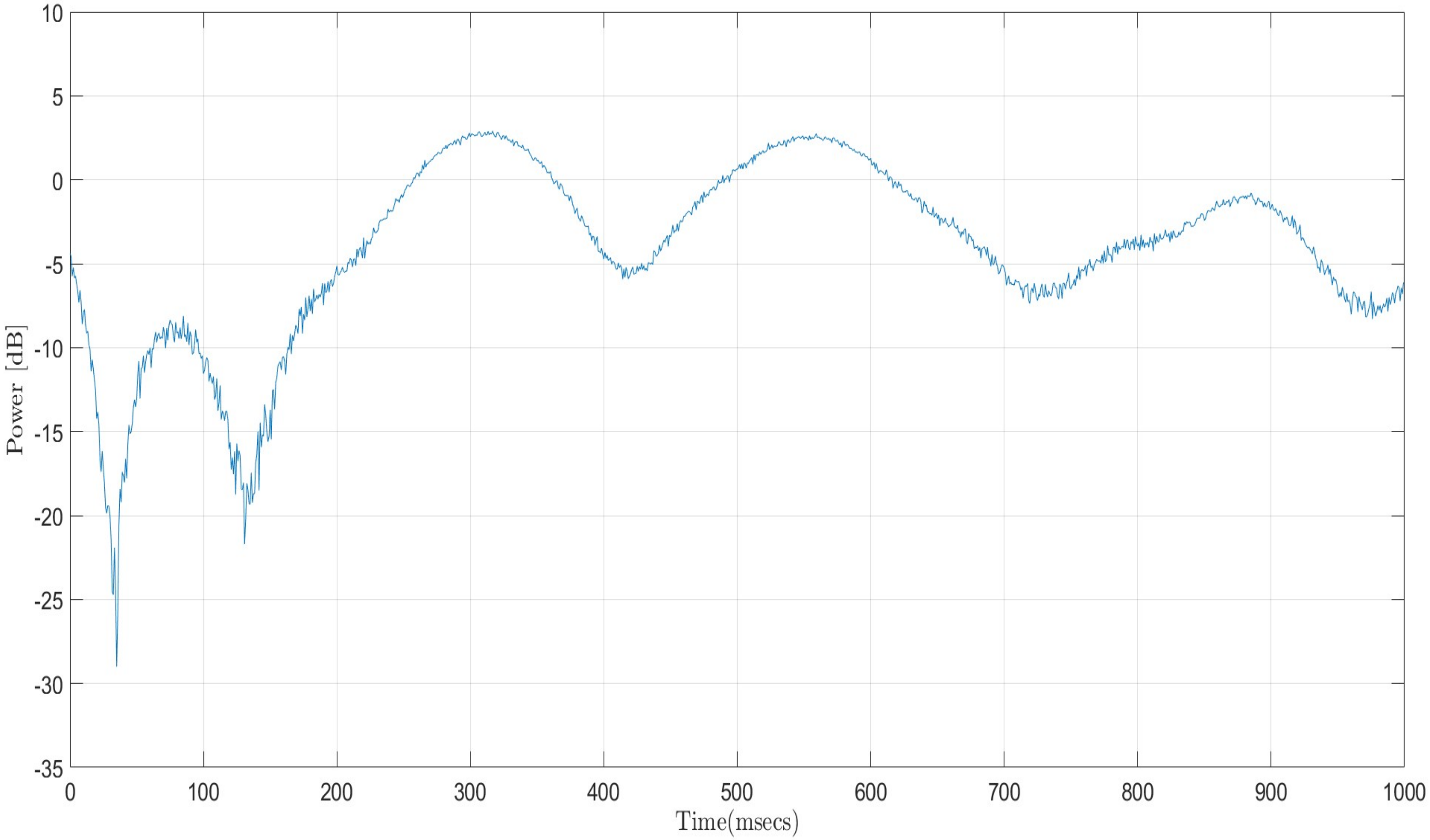
Scenario 3



$$f_o = f_s$$

$where, f_s =$ source frequency, $f_o =$ observed frequency, $v =$ velocity of EM waves, v_s $=$ source or observer velocity.

Output for 10 mph case with 3 multipaths with delays 0.022, 2.33, and 5.314 ns. Train length = 0.5 miles



Min. fade –

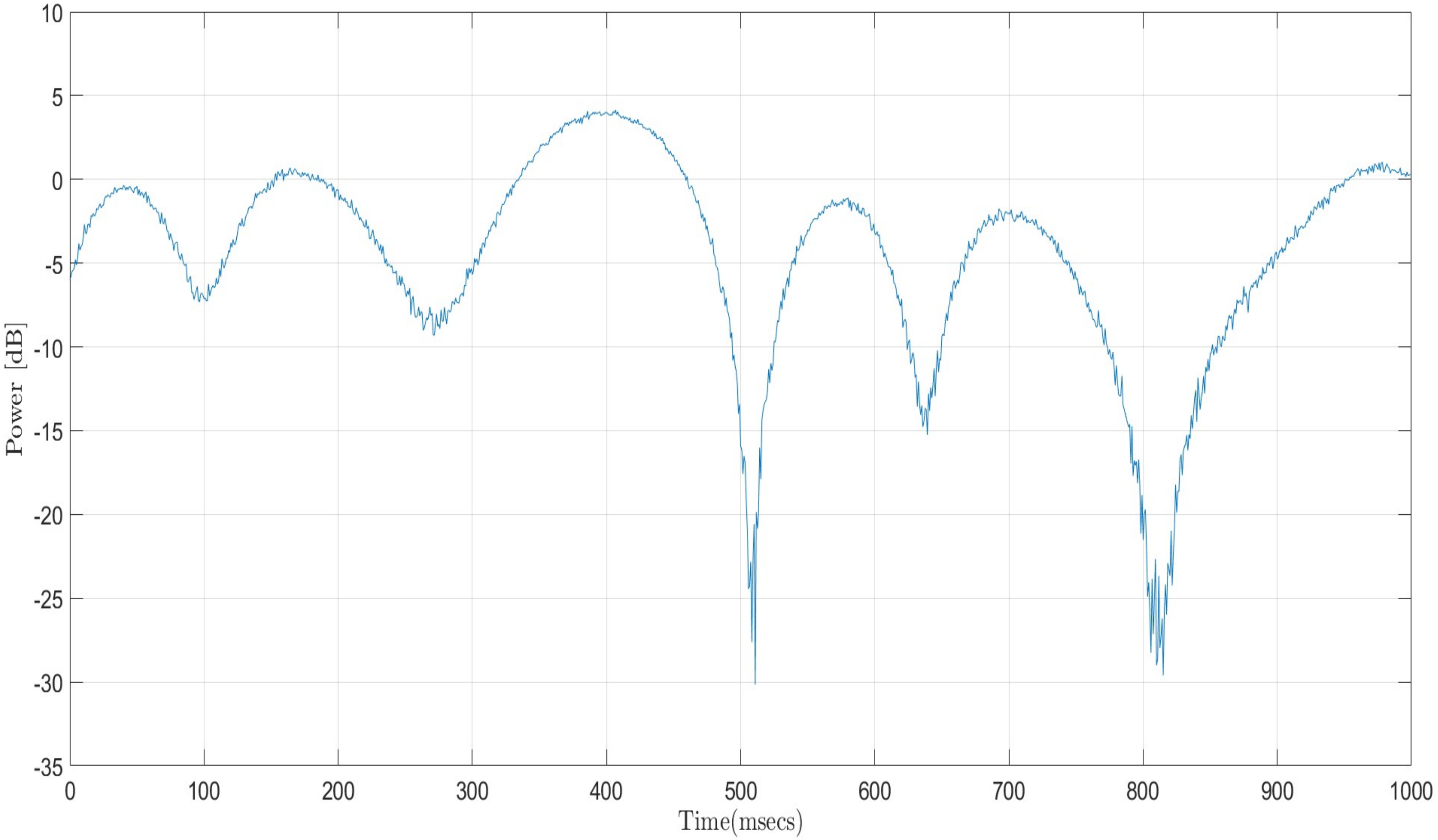
-29.0013 dB

Rise Slope – 14.7 dB/10ms

Fall Slope –

-11.82 dB/10ms

Output for 10 mph case with 3 multipaths with delays 0.003, 0.575, and 2.094 ns. Train length = 5 miles



Min. fade –

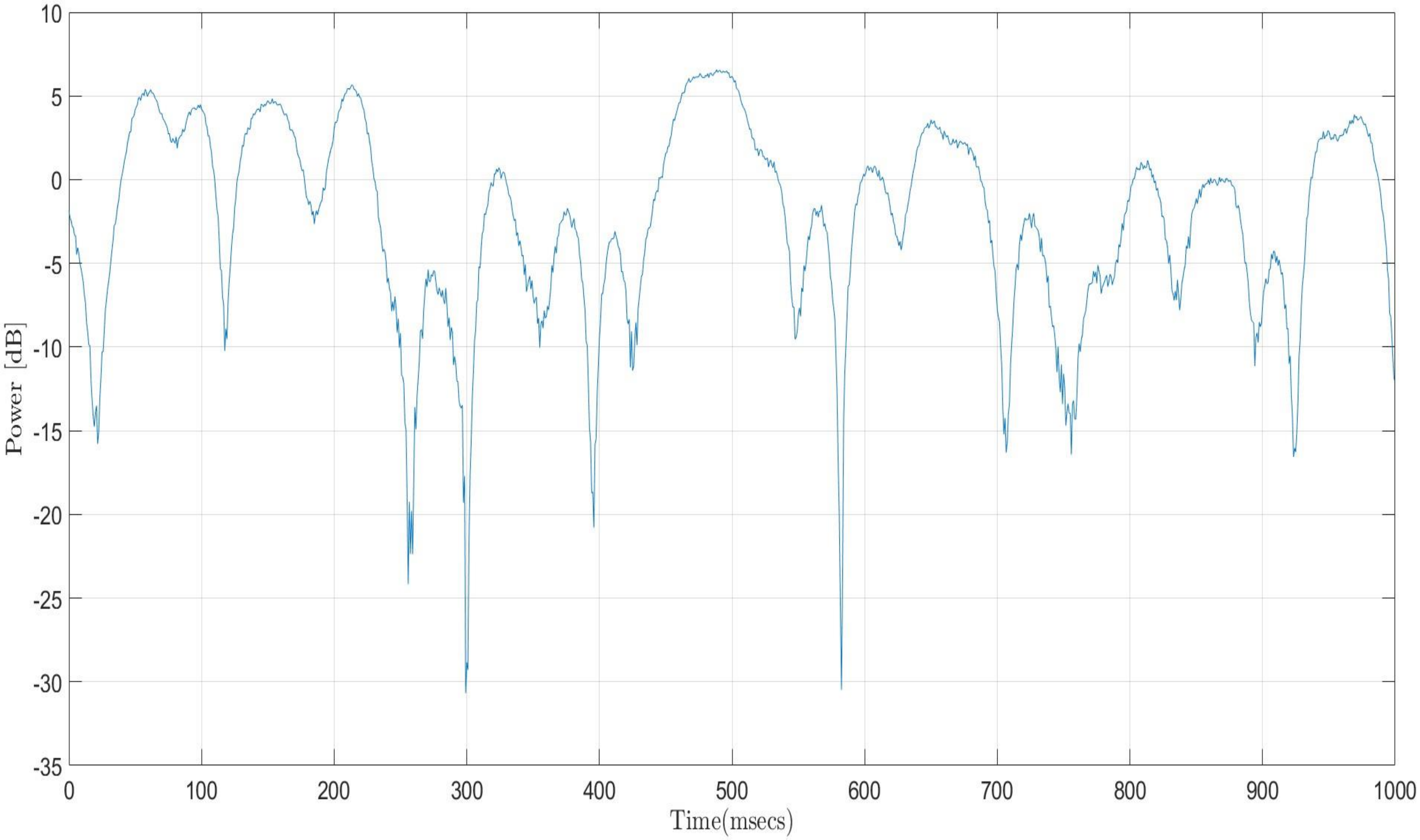
-30.1419 dB

Rise Slope –
18.809 dB/10ms

Fall Slope –

-14 dB/10ms

Output for 30 mph case with 3 multipaths with delays 0.022, 2.33, and 5.314 ns. Train length = 0.5 miles



Min. fade –

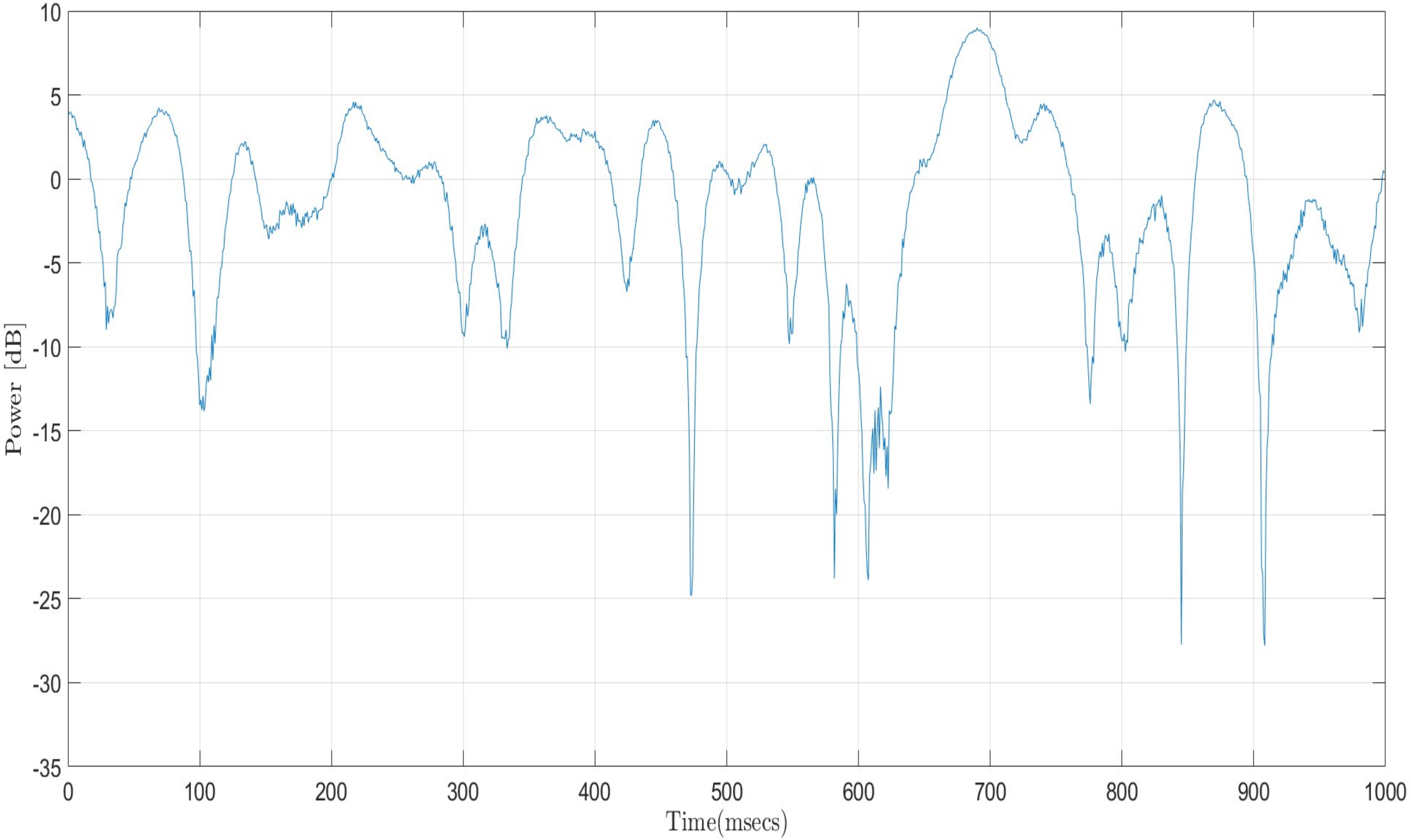
-30.4794 dB

Rise Slope –
28.635 dB/10ms

Fall Slope –

-26.568 dB/10ms

Output for 30 mph case with 3 multipaths with delays 0.003, 0.575, and 2.094 ns. Train length = 5 miles



Min. fade –

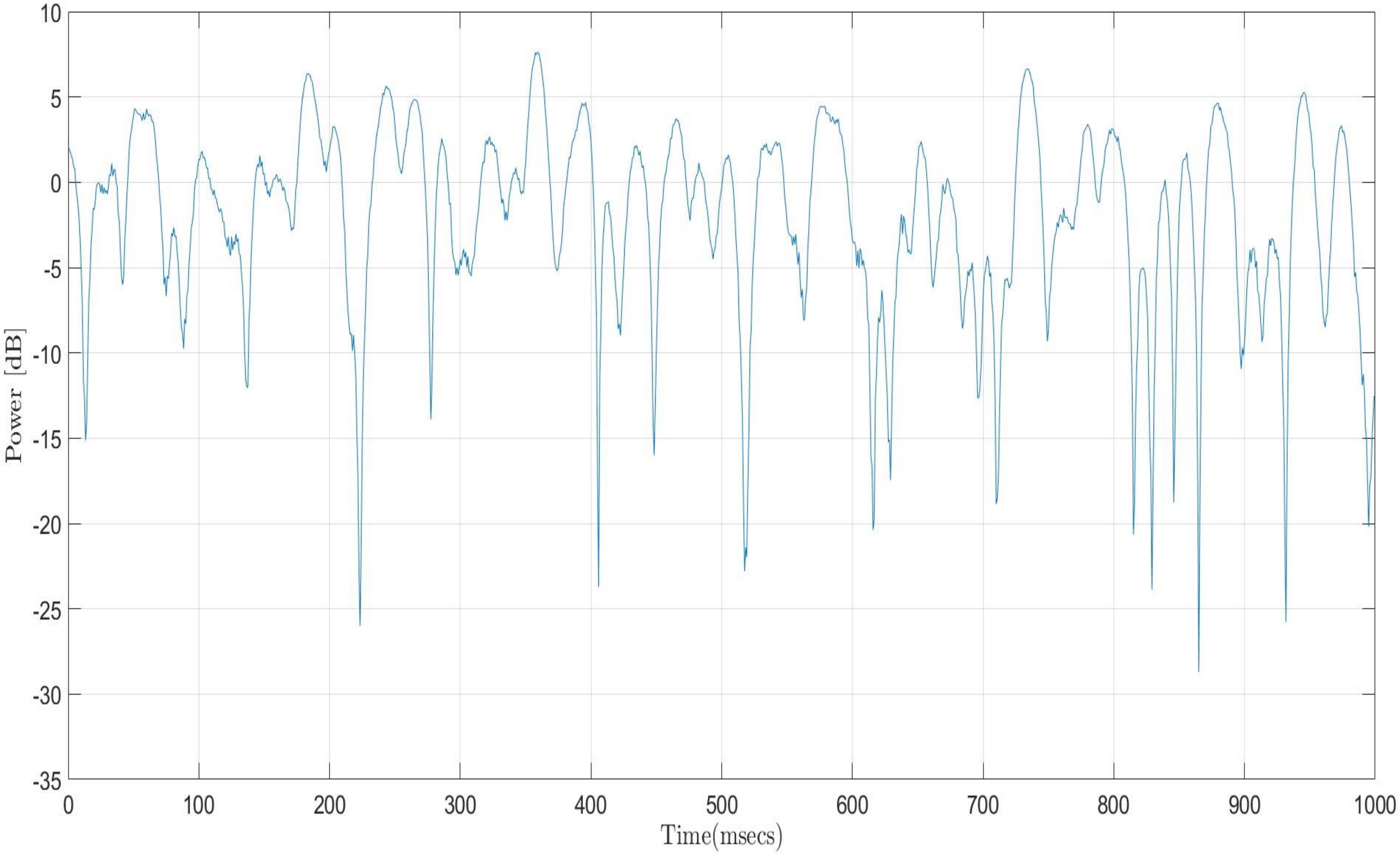
-27.7932 dB

Rise Slop –
21.230 dB/10ms

Fall Slop –

-24.447 dB/10ms

Output for 50 mph case with 3 multipaths with delays 0.022, 2.33, and 5.314 ns. Train length = 0.5 miles



Min. fade –

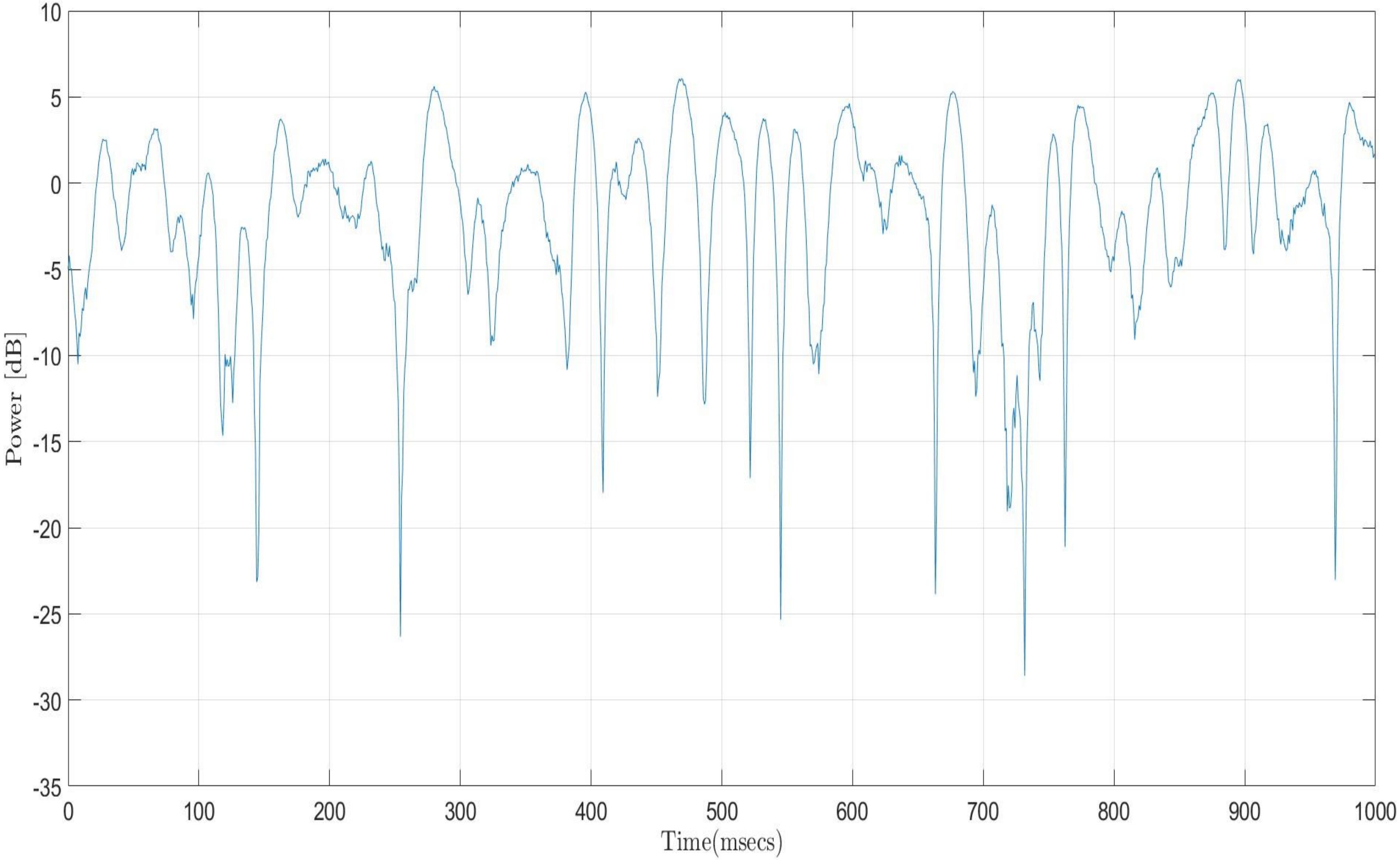
-28.7147 dB

Rise Slope – 32.086 dB/10ms

Fall Slope –

-30.437 dB/10ms

Output for 50 mph case with 3 multipaths with delays 0.003, 0.575, and 2.094 ns. Train length = 5 miles



Min. fade –

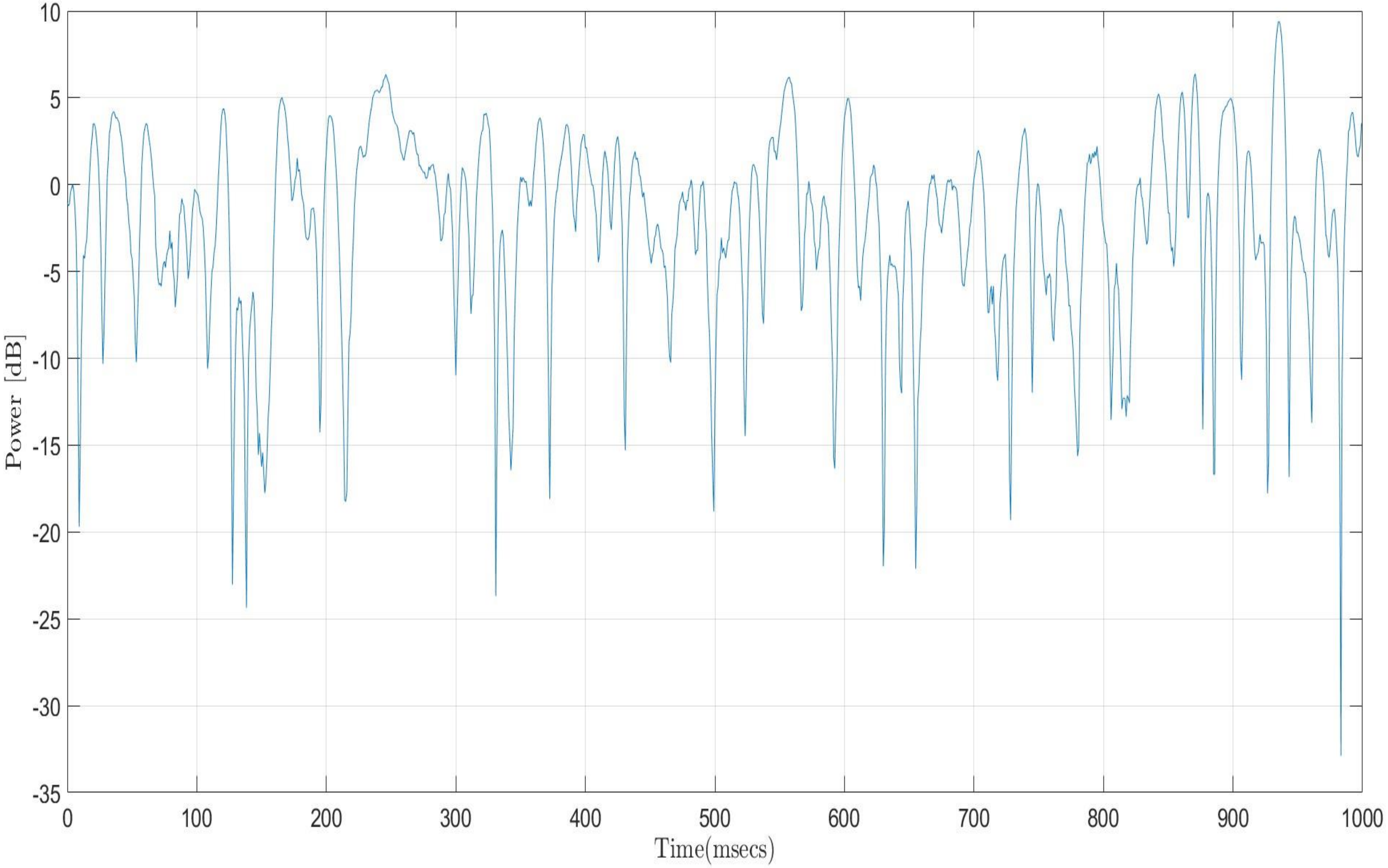
-28.5958 dB

Rise Slop –
25.770 dB/10ms

Fall Slop –

-28.680 dB/10ms

Output for 70 mph case with 3 multipaths with delays 0.022, 2.33, and 5.314 ns. Train length = 0.5 miles



Min. fade –

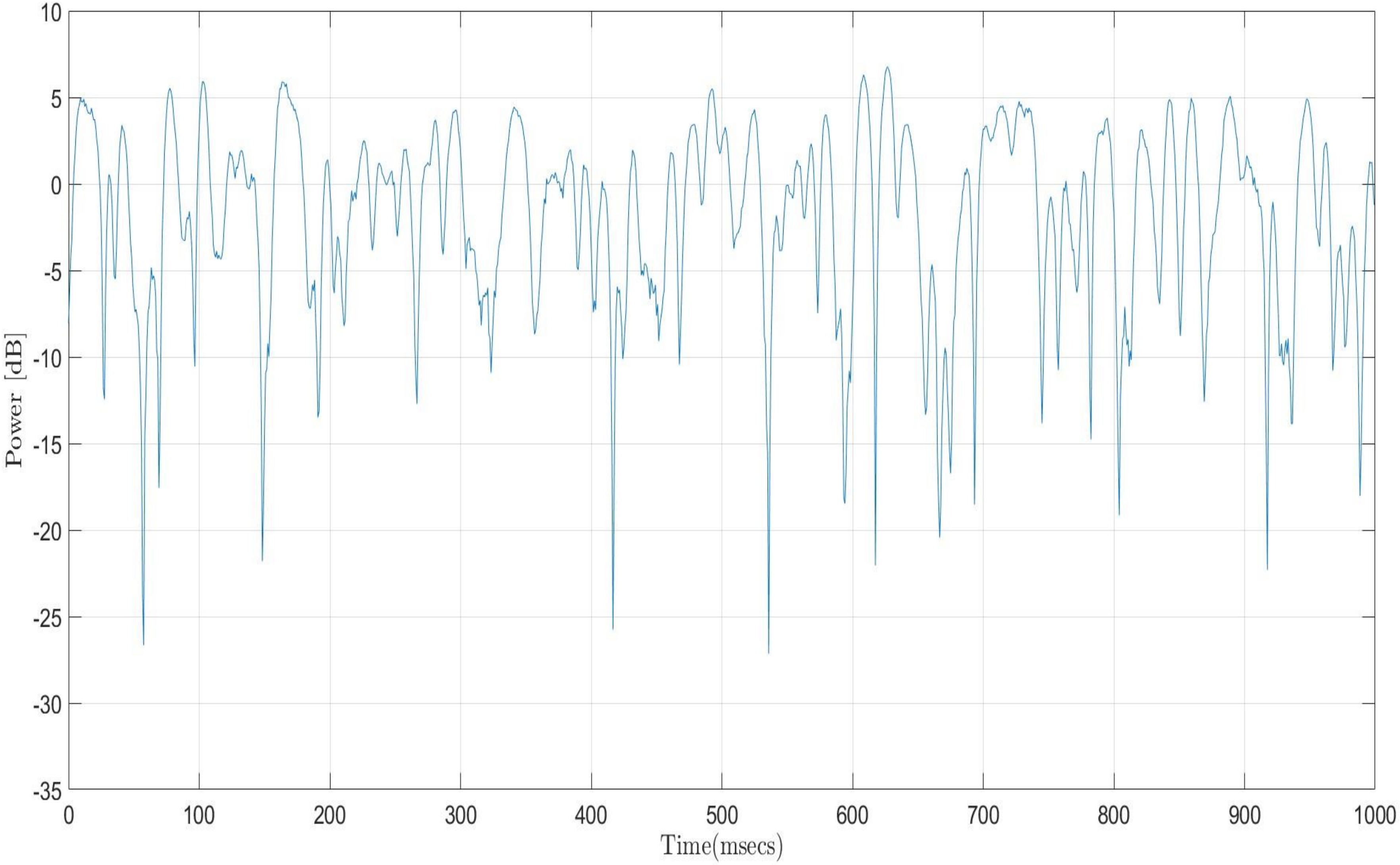
-32.8842 dB

Rise Slop –
14.583 dB/5ms

Fall Slop –

-16.516 dB/5ms

Output for 70 mph case with 3 multipaths with delays 0.003, 0.575, and 2.094 ns. Train length = 5 miles



Min. fade –

-27.1457 dB

Rise Slop –
15.183dB/5ms

Fall Slop –

-14.516dB/5ms