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Hilbert-Huang Transformation based Solar Light Noise Suppression Method

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Abstract

Solar light noise, as the main part of channel noise in outdoor visible light communication (VLC) system, would easily saturate the photon-detector, and dramatically decrease the outdoor VLC system performance. A Hilbert-Huang Transformation based solar light noise suppression method is proposed in this paper, a background light noise measurement system is also designed and implemented to verify the noise suppression method's performance. And the measurement result shows that it could effectively reduce the solar light noise, and improve the VLC system's stability and reliability.

Keywords: *Hilbert-Huang transformation, solar light, noise suppression, visible light communication*

With advantages of light emitting diode (LED) like short on-off delay[1-2], visible light communication (VLC) has become one of the newly improved optical wireless communication technologies. Covering the visible light spectrum from 380nm to 780nm, VLC technology could realize wireless high speed data transportation through modulating light signal parameters like the intensity, phase, frequency, color hue, *etc*[3-6]. VLC technology also has strong anti-interference capability, high security, no electromagnetic interference (EMI), free license, and stronger signal power and no healthy threat over traditional wireless ultraviolet and infrared light communication technologies. Background light from solar light, lunar light, artificial incandescent and inflorescent lights or electronic billboards, as the main source of VLC channel noise, would easily saturate the photon-detector, and dramatically decrease the effective transportation distance, data rate and bit error rate (BER) performance, which make it one of the most urgent problems of outdoor VLC system. Background light noise of VLC channel is simply modeled as a uniformly distributed shot noise[7-9], while characters of direct light from solar light, lunar light, artificial incandescent and inflorescent lights or electronic billboards, or its influence on VLC system are seldom reported.

Background light noise measurement platform is firstly designed and implemented in this paper, and with the measurement data, solar light noise characters are carefully studied. A solar light noise suppression technology based on Hilbert-Huang theory is also proposed, which could effectively reduce the solar light noise influence on outdoor VLC system, and improve the VLC system's anti-interference capability and system stability and reliability.

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1. Background Light Noise Measurement Platform

As shown in Figure 1, background light noise, after filtering by optical filter, will be detected with photon detector Thorlabs PDA10A (with trans-impedance amplifier) and spectrometer HP 3589A to study its spectrum distribution property. Also optical power of background light noise could be measured with photon detector Newport 918D-UV-OD3 and optical dynamometer Newport 1918-C.

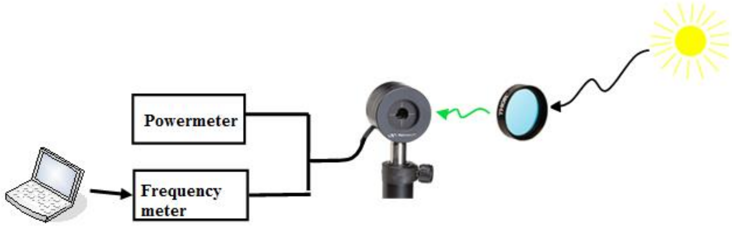


Figure 1. Background Light Noise Measurement Platform

2. Solar Light Noise Character

Specific optical filters Thorlabs FB500-40, Thorlabs FB590-10 and Asahi Spectra ZBPB105 are employed to measure the solar light power varying characteristic under different weather. And the central wavelengths of the optical filters are 500nm, 590nm and 620nm, respectively, while full width at half maximum (FWHM) are 40nm, 10nm and 20nm, respectively. Normalized frequency response curve of the optical filters are given in Figure 2.

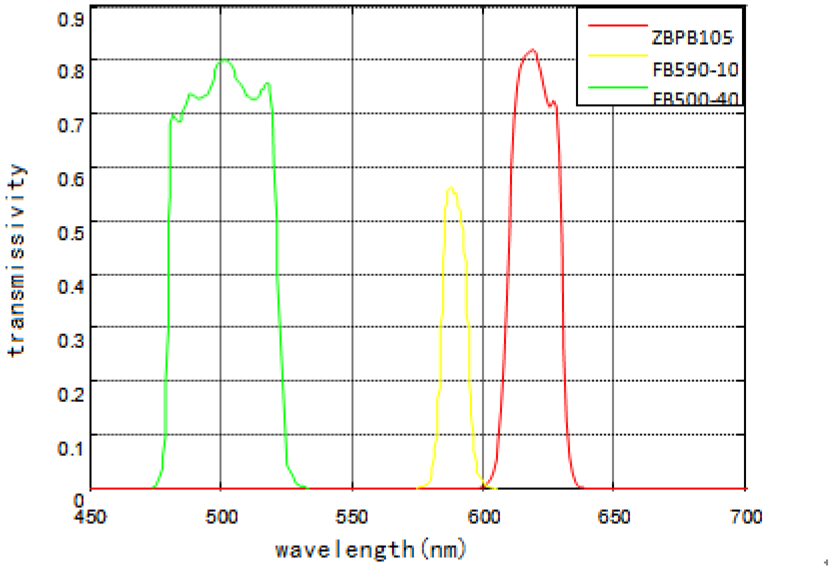


Figure 2. Normalized Frequency Response Curve of the Optical Filter

Photon-detector, with an effective area of 1 cm^2 and a field of view (FoV) of 15^o, is employed to measure solar light intensity under different weathers (sunny, cloudy and overcast, actually) in Shenzhen in December. Figure 3 shows the solar light intensity during a whole day, while the photon-detector pointing to the sun directly. It is easy to find that clouds would result in dramatical vibration of the solar light intensity, and the solar light intensity during a whole day would be represented as a polynomial fitting,

$$S = -0.069T^2 + 1.8062T - 9.5337, \tag{1}$$

where T in hours means the different time during a whole day.

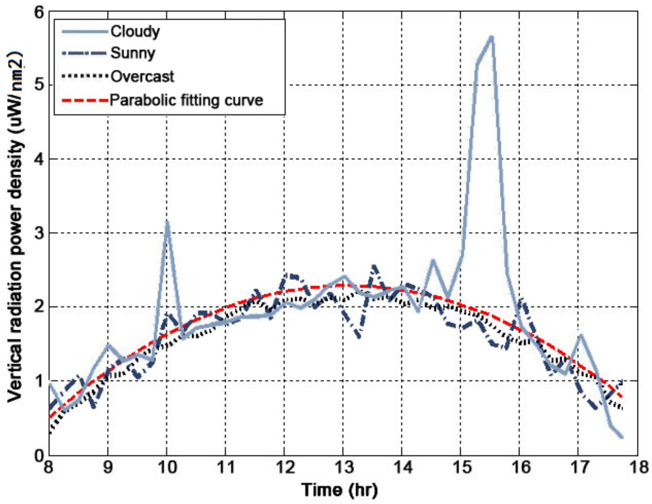
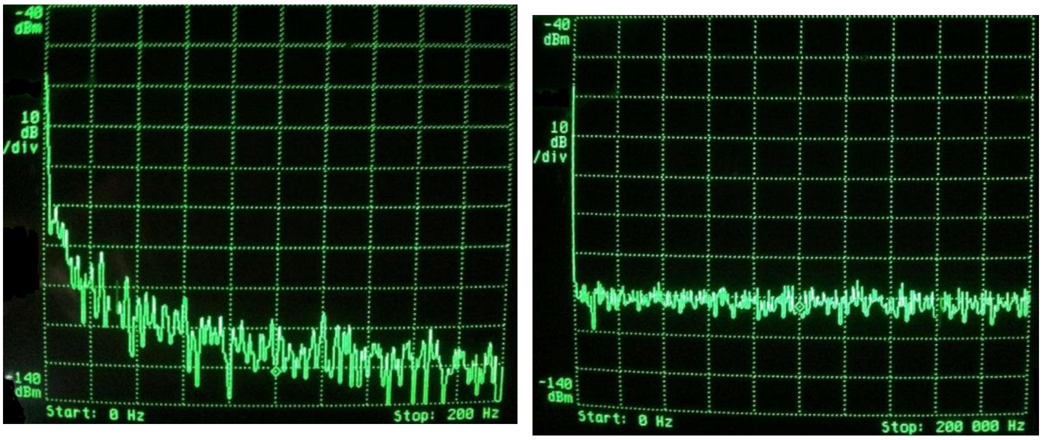


Figure 3. Measured Vertical Solar Power Density vs. Time



(a) Power spectrum distribution in 0~200Hz

(b) Power spectrum distribution 0~200KHz

Figure 4. Power Spectrum Distribution of Solar Light

Solar light power spectrum distribution curves with photon-detector directly pointing to the sun are shown in Figure 4, and we can find that the solar light power is centrally distributed in the low frequency area, diminishes while the frequency rising up, and finally fixed around -110dBm. And it would be feasible to employ a low-pass filter or raise the demand light signal frequency to avoid the interference resulting from the solar light.

3. Sunlight Suppression Technology based on Hilbert-Huang Transformation

Interference resulting from the atmospheric instability, cloud shadow, and many other environment related factors, the solar light is quite variable during a whole day. Therefore, the solar light noise would be a nonlinear, instable signal, and it would be very effective to employ a high-pass filter to suppression the solar light noise. While the traditional IIR, FIR and wavelet filters, which are all Fourier transformation based, would filter the low frequency part of solar light, but may bring some inevitable interference on the filtered light signal. And interpolation will be needed to analyze the solar light noise in the frequency domain, which may also bring some inevitable interference on the original light signal, and attenuate the suppression effect. In this paper, we propose a method based on the Hilbert-Huang Transform (HHT) and Empirical Mode Decomposition (EMD) to suppress the solar light noise, it firstly decomposes the received signal into several Intrinsic Mode Functions (IMF), and generates the Hilbert spectrum of each mode function with respect to the time frequency distribution, and finally eliminates or suppressed solar light noise interference to the outdoor VLC system, effectively.

The EMD method would decompose the signal to one group of the IMF with different time scale, which meets one of the following two conditions,

1. For any data, the number of the extreme points is the same to the zero crossing points, or differs by one at most.
2. The mean value of the envelope line, made of the local maximum and minimum points, are equal to zero.

The original signal could be represented by the sum of a group of IMF and a residual, and it also means that the EMD decomposition is based on the original signal, instead of the primary basis functions. The IMF serial, after EMD decomposition, is the result of multi-band pass filtered, and would show layer by layer filtered characteristic from short to long in time domain, and from low to high in frequency domain. Therefore, this also shows the multi resolution analyzing capability of the EMD decomposition.

The multi resolution analyzing and reorganizable capabilities of EMD decomposition would surely show a new way to eliminate or suppress the background noise mixed with the original signal. When the noise could be treated as one or several IMF components, time-frequency filter could be employed directly. And the time-frequency filter with n IMF components is,

$$x_{lk}\left(t\right)=\sum_{i=k}^{n}C_i\left(t\right)+R_n\left(t\right) \tag{2}$$

and the high pass time frequency filter for noise with merely low frequency part is

$$x_{hk}\left(t\right)=\sum_{i=1}^{k}C_i\left(t\right) \tag{3}$$

and the band pass time frequency filter for noise with both low and high frequency part is

$$x_{bk}\left(t\right)=\sum_{i=k}^{h}C_i\left(t\right) \tag{4}$$

The above time frequency filter could set some given IMF components to zero, and is absolutely effective when the noise is made up with one or several IMF components. But when the original signal and noise are mixed together in one or several IMF components, the time frequency filter may remove some parts of the demand signal while suppress the noise, and this would surely destroy the integrity of the original signal, and weaken the correctness of the following processing.

Similar with the wavelet domain noise suppression method, we could employ a modified IMF component method with some given fixed scales, which would keep the integrity of the original signal while suppress the noise. The received signal could be represented as n IMF component after EMD decomposition, and a proper threshold is chosen for each IMF component to truncate, finally, the signal could be reorganized as,

$$x\left(t\right)=\sum_{i=1}^{n}C_i\left(t\right)+R_n \tag{5}$$

And the threshold according to the wavelet noise suppression theory is,

$$\begin{aligned} \tau_i &= \sigma_i \sqrt{2\log(n)} \\ \sigma_i &= MAD_i / 0.6745 \end{aligned} \tag{6}$$

where σ_i is the noise intensity in the i^{th} layer, MAD_i is the median absolute deviation of the IMF component in the i^{th} layer, which is

$$MAD_i = Median\left\{\left|C_i(t) - Median\{C_i\}\right|\right\} \tag{7}$$

and the estimated hard threshold of IMF component in the i^{th} layer is

$$C_i(t) = \begin{cases} C_i(t) & |C_i| \geq \tau_i \\ 0 & |C_i| < \tau_i \end{cases} \tag{8}$$

And the estimated soft threshold is

$$C_i(t) = \begin{cases} \mathrm{sign}(C_i(t))\left(\left|C_i(t) - \tau_i\right|\right) & |C_i| \geq \tau_i \\ 0 & |C_i| < \tau_i \end{cases} \tag{9}$$

Therefore, shown in the following flowchart, the solar light noise suppression technology would be implemented through the coming steps,

1. Decompose the received light signal, polluted by the solar light noise, into different IMF components;
2. According to the different noise source and their characteristics, employ the time frequency filter based on the EMD, or estimated hard or soft threshold to suppress the noise in different IMF components;
3. Reorganize the demand signal with the processed IMF components.

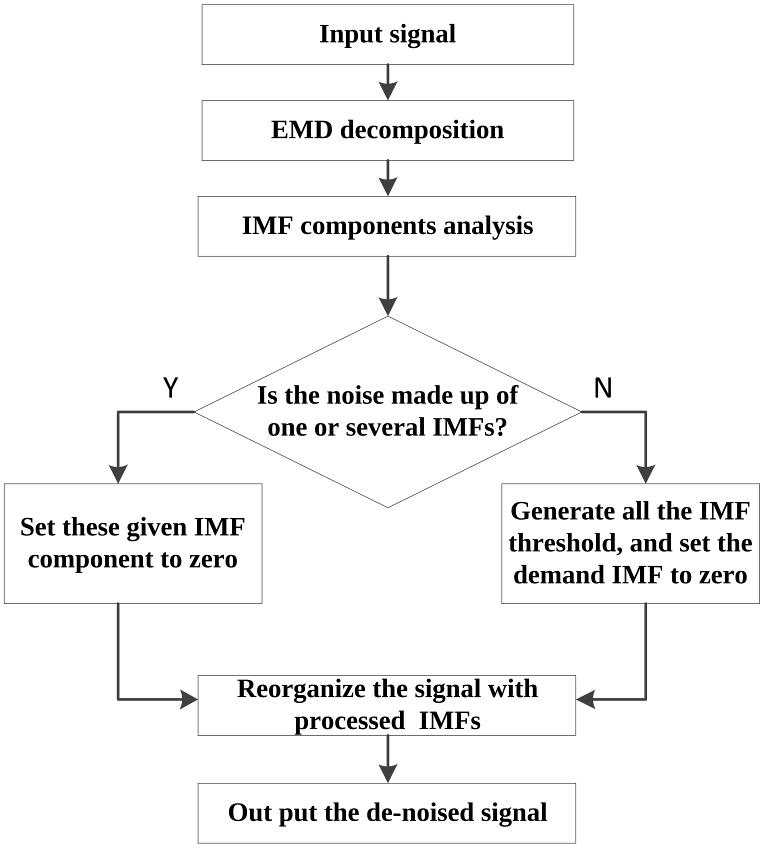


Figure 5. Optical Signal De-Noising Calculation Flow based on EMD

4. Measurement Results

In this paragraph, measured solar light results are employed to prove the effectiveness of Hilbert-Huang based background light noise suppression method. Solar light noise power is widely distributed through 0~200Hz, while concentrated distributed near 0Hz through 0~200KHz, which is perfectly noticeable for the Hilbert-Huang method.

Under different weather conditions, measured solar light result in time domain, EMD decomposition and Hilbert spectrum are shown in the following figures.

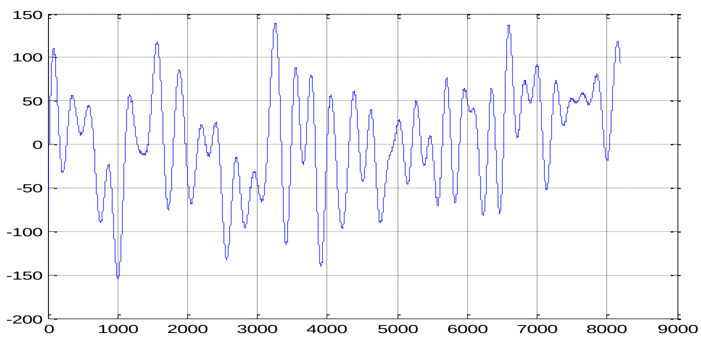


Figure 6. The Measured Time Domain Waveform for Sun Background Noise (Sunny Weather)

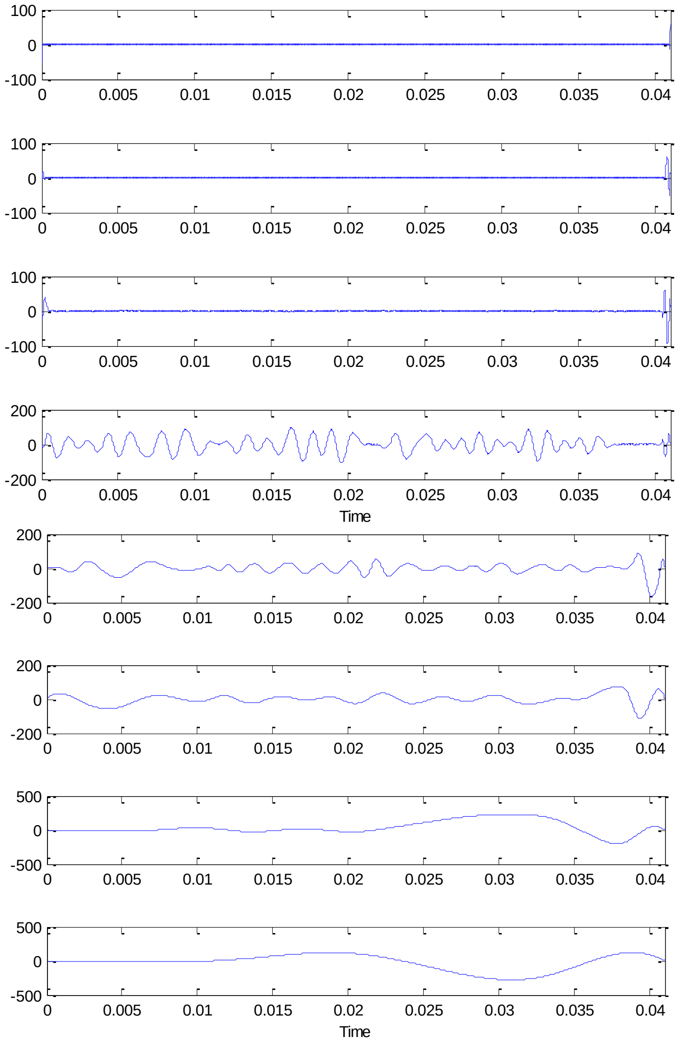


Figure 7. IMF Component (Sunny Weather)

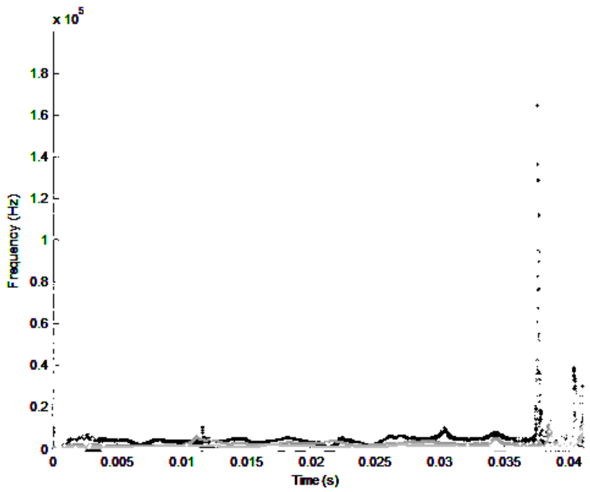


Figure 8. Hilbert Spectrum (Sunny Weather)

And the signal power spectrum with estimated threshold noise suppression method is shown in Figure 9.

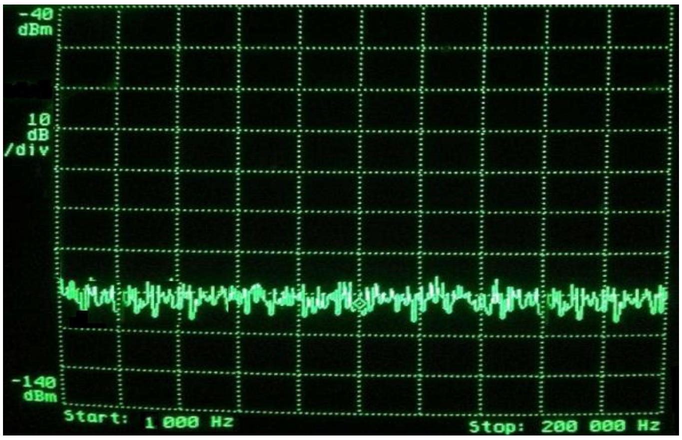


Figure 9. Power Spectrum Distribution with Hilbert-Huang Filter (Sunny Weather)

Then the results under cloudy weather are shown below.

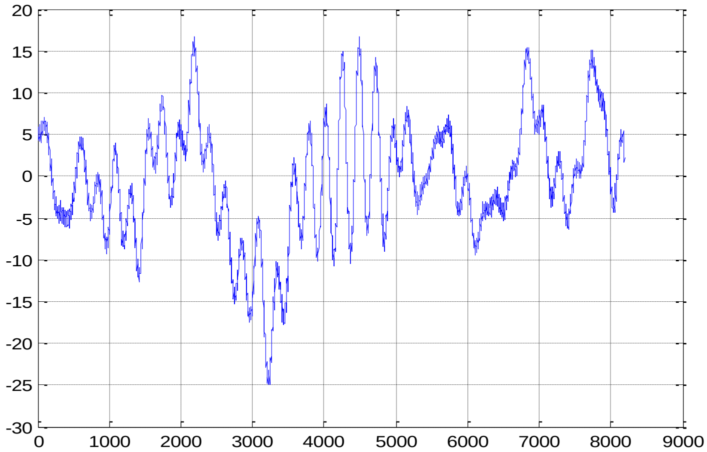
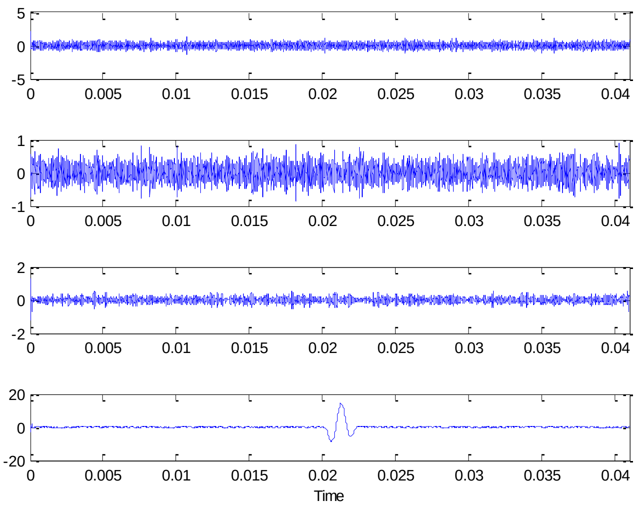


Figure 10. The Measured Time Domain Waveform for Sun Background Noise (Cloudy Weather)



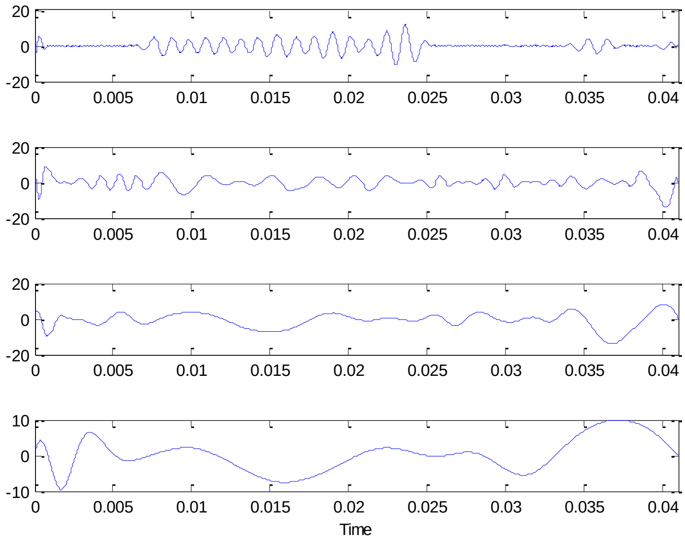


Figure 11. IMF Components (Cloudy Weather)

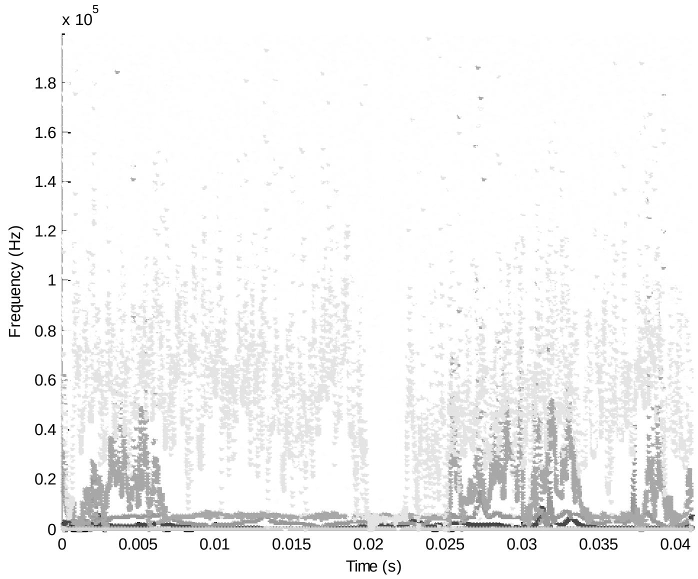


Figure 12. Hilbert Spectrum (Cloudy Weather)

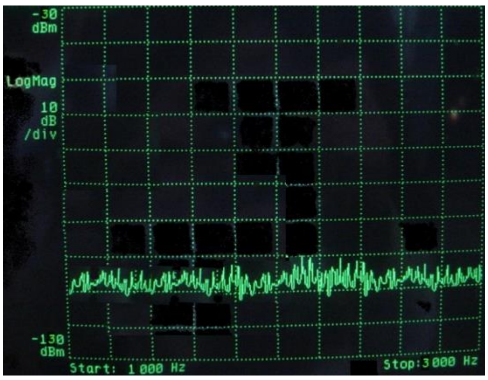


Figure 13. Power Spectrum Distribution with Hilbert-Huang Filter (Cloudy Weather)

The results under Overcast weather are shown below.

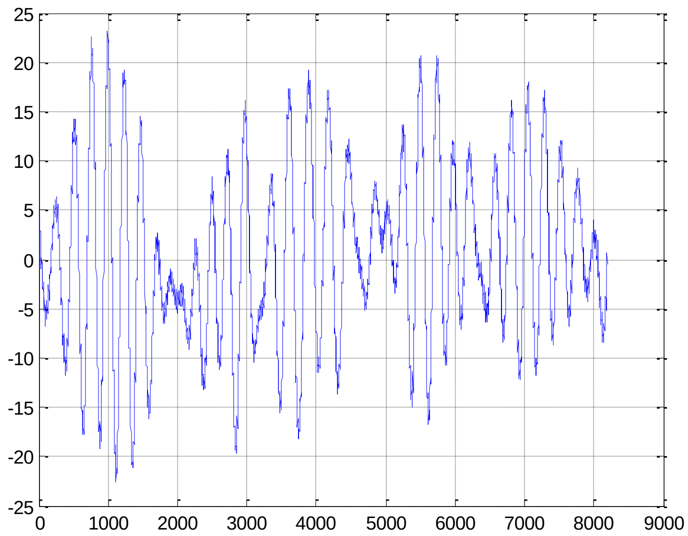


Figure 14. The Measured Time Domain Waveform for Sun Background Noise (Overcast Weather)

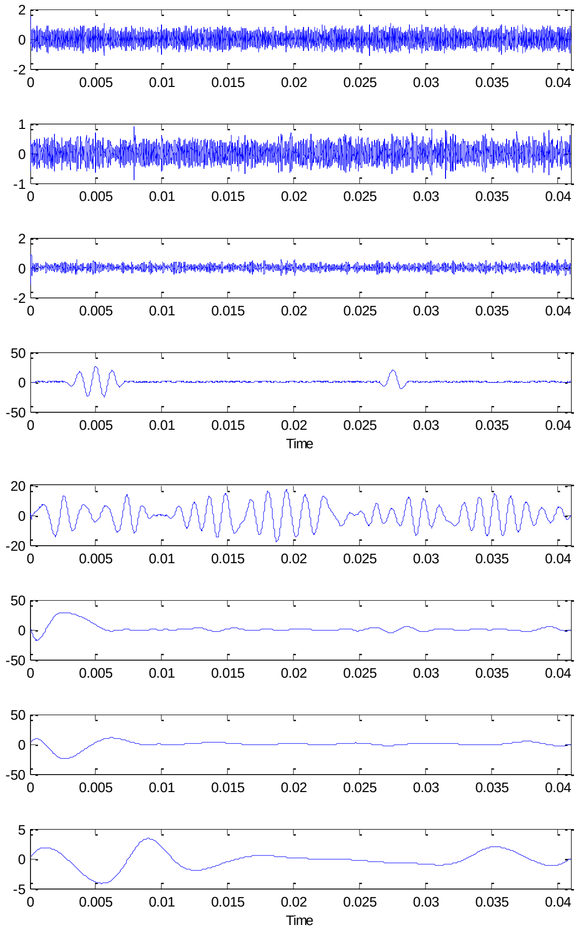


Figure 15. IMF Components (Overcast Weather)

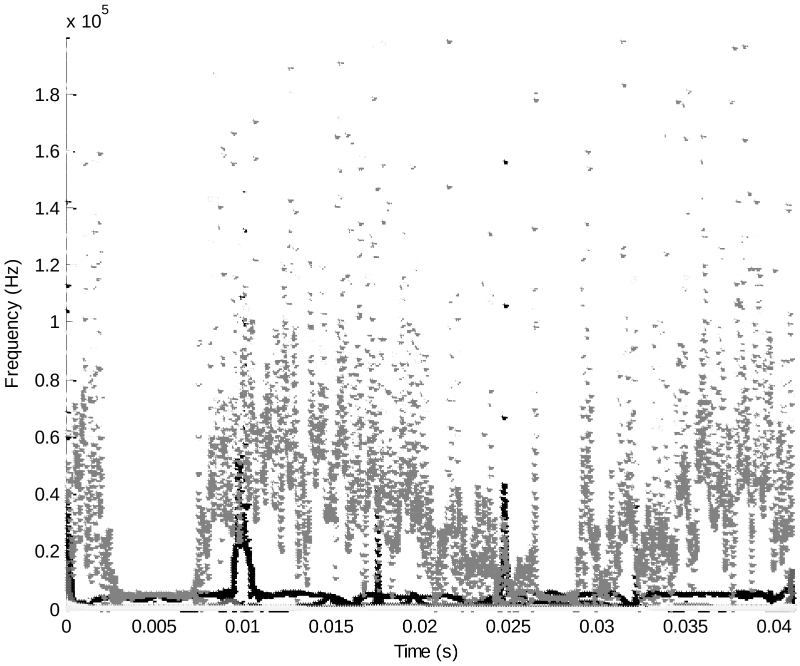


Figure 16. Hilbert Spectrum (Overcast Weather)

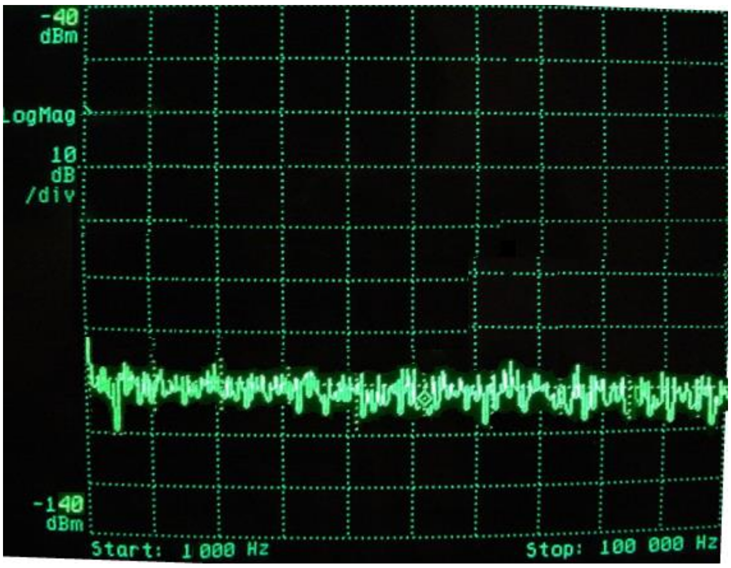


Figure 17. Power Spectrum Distribution with Hilbert-Huang Filter (Overcast Weather)

5. Conclusion

With measurement results of newly designed background light noise measurement platform, solar light noise character is carefully studied in this paper, and solar light noise suppression technology based on Hilbert-Huang theory is also proposed, which could effectively reduce the solar light noise influence on outdoor VLC system, and improve the VLC system' s anti-interference capability and system stability and reliability.

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