# Random Noise and Coherent Interference Estimation of MT Instrument

Chen Rujun, He Zhanxiang, He Lanfang, Liu Xuejun
*Non-seismic Survey, Bureau of Geophysical Prospecting, CNPC, Zhuozhou, 072751, China*
*chrujun@yahoo.com.cn, hezhanxiang-bgp@163.com, cdithlf10@263.net, xuejunliu@163.com*

## Abstract

*Random noise and coherent interference are major factors determine the performance of MT instrument. Based on auto and cross power spectrum of channels inside MT instrument, procedure is developed to estimate noise and coherent interference inside MT instrument. At first, short circuited input is applied to all channels of MT instrument. Coherent interference inside instrument is estimated by signal to noise ration (SNR) of arbitrary two channels. Secondly, all channels of instrument are connected to same random noise input. Random noise inside instrument is estimated by noise spectrum of arbitrary two channels. MTU-5P of system 2000 is used for experiment. Experiment result shows that coherent interference, which is about 8 times random noise, exist in TS5 data; Normalized power spectrum density of whites noise is below -150dB; it shows excellent performance in wide frequency band, but coherence interference in some band need to be minimized.*

## 1. Introduction

Random noise and coherent interference are major factors determine the performance of magnetotelluric (MT) instrument. Noise performance can be improved by adopting chopper stabilized or commutating auto zero amplifiers[1]. Constable et al. adopted chopper stabilized amplifiers in marine MT instrument, good performance was achieved[2]. Modern MT instrument is move and more complicated, GPS OEM board and embedded computer system may contribute serious coherent interference to MT instrument, especially when input signal is weak. Parallel test is often used to evaluated performance of MT instrument[2], but it is impossible to discovery coherent interference inside MT instrument. Because it enhance signal to noise ratio (SNR) of instrument. This paper aims at the procedure to evaluate noise and coherence interference of MT instrument, offer a reliable way to estimate above factors from spectral analysis result.

## 2. Principle of random noise and coherent interference estimation by spectral analysis

Based on principle of random signal and noise which input and output a linear system, a random signal or determined signal is used as same input for all channels of MT instrument, coherence, SNR and noise spectrum of instrument's two channel can be derived from auto power and cross power of corresponding channels.

Let signal source as $s_k$, it is measured by two channel simultaneously. Measurement result is [$x_k$] and [$y_k$], transfer function of above two channels is $H_1$ and $H_2$ respectively. Independent noise $n_{1k}$ and $n_{2k}$ are added in signal before signal pass above two channel. According to linear system theory, exist the following formula:

$$\begin{cases} X(z) = H_1(z)[N_1(z) + S(z)] \\ Y(z) = H_2(z)[N_2(z) + S(z)] \end{cases} \quad (1)$$

Let $H_1$ and $H_2$ as linear digital transfer function $H_1(z)$ and $H_2(z)$, above transfer functions exist no zero point at unit circle $z = e^{j\omega}$, the following transform relation exist:

$$Y(z) = \frac{H_2(z)}{H_1(z)}[X[z] + H_1(Z)(N_2(z) - N_1(z))] \quad (2)$$

Let:

$$H(z) = \frac{H_2(z)}{H_1(z)}, N(z) = H_1(z)[N_2(z) - N_1(z)] \quad (3)$$

we have $Y(z) = H(z)[X[z] + N(z)]$ (4)

Suppose noise $n_k$ is independent of $x_k$ and $y_k$, cross power $\Phi_{xn}(z)$ and $\Phi_{yn}(z)$ equal to zero. Then we have the following equation:

$$\Phi_{xy}(z) = H(z)\Phi_{xx}(z) \quad (5)$$

$$\Phi_{yy}(z) = |H(z)|^2 [\Phi_{xx}(z) + \Phi_{nn}(z)] \quad (6)$$

From $\Phi_{xy}(z)$ , $\Phi_{xx}(z)$ , $\Phi_{yy}(z)$ , expressions of coherence, transfer function $H(z)$, noise power spectrum and SNR can be expressed as the following [3]:

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$$\Gamma_{xy}^2(z) = \frac{|\Phi_{xy}(z)|^2}{\Phi_{xx}(z)\Phi_{yy}(z)} = \frac{1}{1+1/SNR(z)} \qquad (7)$$

$$H(z) = \frac{\Phi_{xy}(z)}{\Phi_{xx}(z)} \qquad (8)$$

$$\Phi_{nn}(z) = \Phi_{xx}(z)[\Gamma_{xy}^2(z) - 1] \qquad (9)$$

$$SNR(z) \triangleq \frac{\Phi_{xx}(z)}{\Phi_{nn}(z)} = \frac{\Gamma_{xy}^2(z)}{1-\Gamma_{xy}^2(z)} \qquad (10)$$

Expressions (7) ~ (10) show that coherence of 2 channels is near to 1 when noise power spectrum is near to zero, and the transfer function keep finite value; The coherence between two channels is near to 0 when noise spectrum increase or transfer function *H(z)* is near to 0. Based on coherence between two channels, we can judge measuring result caused by signal or noise from 2 channels[3].

For MT instrument, we apply following procedure to estimate noise and coherence interference inside channels of instrument. At first, short circuited input is applied to all channels of a given MT instrument, for arbitrary two channels, coherence, SNR, and noise spectrum, auto power, cross power are calculated for above channels. Coherence between each channel is near to zero if just random noise exists inside MT instrument. If coherence between two channels is great than 0.8, significant coherence interference exist inside instrument. noise and coherence interference can be evaluated by check auto power and estimated noise power between two channels . Secondly, all channels of instrument are connected to same white noise input or other definite signal, above parameters are calculated again, estimated noise power and SNR offer better estimation of instrument's noise because second step let instrument's status near working environment.

## 3. Spectral analysis method

The auto power spectrum of a stationary random process $x_n$ is related to the auto correlation sequence $R_{xx}(m)$ by the discrete-time Fourier transform[4]. It is given by

$$S_{xx}(\omega) = \sum_{m=-\infty}^{\infty} R_{xx}(m)e^{j\omega m} \qquad (11)$$

It can be expressed as a function of physical frequency $f$ by relation $\omega = 2\pi f / f_s$, where $f_s$ is the sampling frequency.

$$S_{xx}(f) = \sum_{m=-\infty}^{\infty} R_{xx}(m)e^{-2\pi j f m / f_s} \qquad (12)$$

The functions

$$P_{xx}(\omega) = \frac{S_{xx}(\omega)}{2\pi} \text{ and } P_{xx}(f) = \frac{S_{xx}(f)}{2\pi}$$

from the above expressions are defined as the auto power spectral density (PSD). The idea is same for cross power spectrum and cross power spectral density. From expressions (7) ~ (10), it is obvious that power spectral density can also by used to calculate coherence, noise spectrum density and SNR.

Spectrum estimation methods are categorized as nonparametric methods, parametric methods and subspace methods[5]. Nonparametric methods are those in which the PSD is estimated directly from the signal itself. The simplest such method is the periodogram. An improved version of the periodogram is Welch's method[6]. Parametric methods are those in which the PSD is estimated from a signal that is assumed to be output of a linear system driven by white noise. Examples are the Yule-Walker autoregressive (AR) method and Burg method. Subspace methods generate frequency component estimates for a signal based on an eigen-analysis or eigen-decomposition of the correlation matrix. Examples are the multiple signal classification (MUSIC) method or the eigenvector (EV) method. Advantages of Nonparametric methods are fast computation speed, linear estimation PSD. Parametric methods are better for short time series, but none linear effect is a problem for some usage[5]. Subspace methods are best suited for line spectra, are effective in the detection of sinusoids buried in noise. Because enough data can be acquired for MT instrument, we chose Welch's method for spectral analysis method. Welch's method consists of dividing the time series data into (possible overlapping) segments, computing a modified periodogram of each segment, and then averaging the PSD estimates. In noise PSD and coherence interference estimation of MT instrument, the data is divided into segments with 60% overlap between them. Segment length is 8192 for time series 5 (TS5, 15Hz sample rate) data, 1024 for time series 3 (TS3, 2400Hz sample rate) and time series 4 (TS4, 150Hz sample rate) data. A hamming window is used to compute the modified periodogram of each segment.

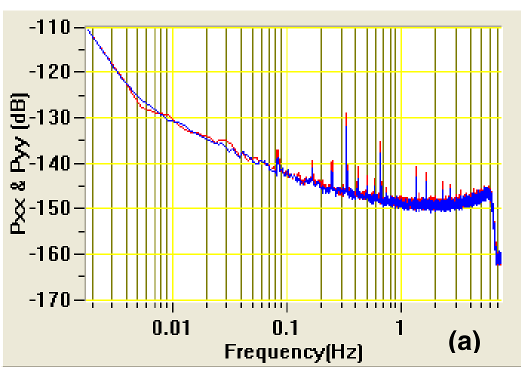
## 4. Random noise and coherent interference estimation experiment

Bureau of Geophysical Prospecting (BGP) have applied V5-2000 system for MT exploration for several years. More than 10,000 MT station's data are acquired for each year. V5-2000 unit is used for experiment. At first, All channel's input connector are connected to ground connector for each V5-2000 unit to do short circuited input test. All kinds of filter setting and gain setting combination are tested for complete performance evaluation. Secondly, the dual random noise generator produced by same manufacturer is used as signal source, electrical and magnetic channels are given same random signal source. To get reliable estimation result, 6 hours of data acquisition time is required. Auto PSD and cross PSD of channels of instrument according to Welch's method are computed at first, transfer function, SNR, coherence, noise PSD are then calculate according to expressions (7) ~ (10).

A software developed under Visual C++ environment realizes time series input, time series display in numerical and waveform style, spectral analysis setting input, PSD and other quantities calculation, spectral analysis result display, and so on. After time series is prepared, the software read selected time series data and do spectral analysis according to user's command. Based on auto PSD, transfer function, coherence, SNR, and noise PSD result for short circuited input test and rand signal input test, instrument's random noise and coherence interference level are determined.

## 5. Experiment result and analysis

The following is testing result of experiment. Time series data are normalized by full scale A/D output before spectral analysis.



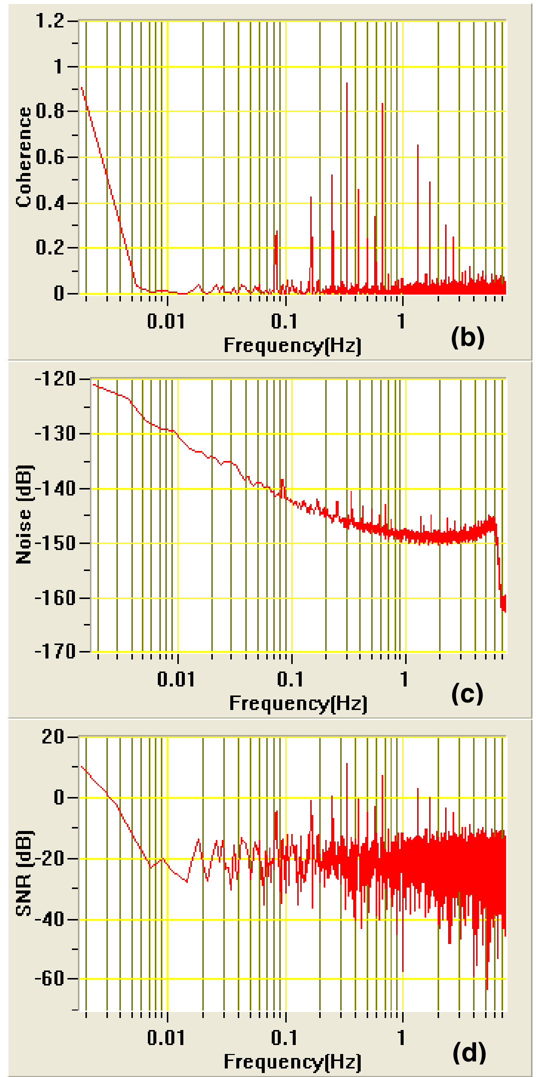




Figure 1. **Short circuited input test result for TS5 time series data (Sample frequency: 15Hz; (a): auto PSD of Ex (red line) and Ey (blue line); (b): coherence between Ex and Ey; (c): noise PSD between Ex and Ey; (d): SNR between Ex and Ey)**

Figure 1. is short circuited input test result for TS5 time series data. FFT length is 8192 for PSD estimation. Figure 1. (a) shows auto power spectral density (PSD) of Ex and Ey. It's obvious that coherent interference exist in pass band of TS5. Coherence in Figure 1. (b) verifies the existence of coherent interference. Coherence increase when frequency is less than 0.005Hz, this phenomenon may caused by temperature drift of instrument.

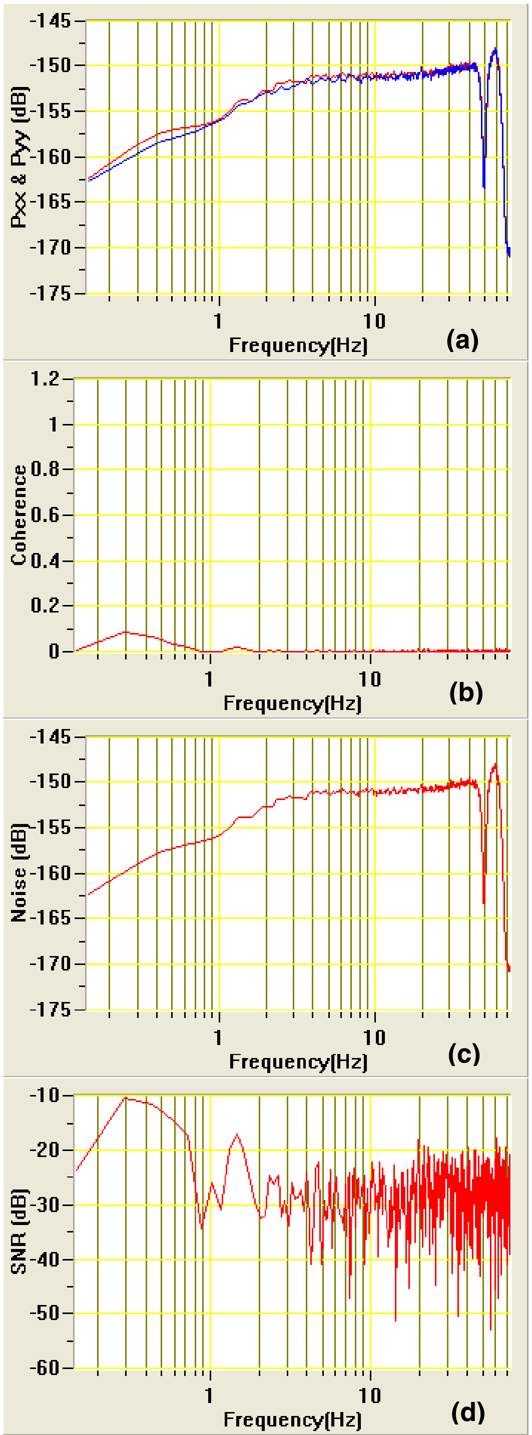



Figure 2. **Short circuited input test result for TS4 time series data (Sample frequency: 150Hz; (a): auto PSD of Ex (red line) and Ey (blue line); (b): coherence between Ex and Ey; (c): noise PSD between Ex and Ey; (d): SNR between Ex and Ey)**

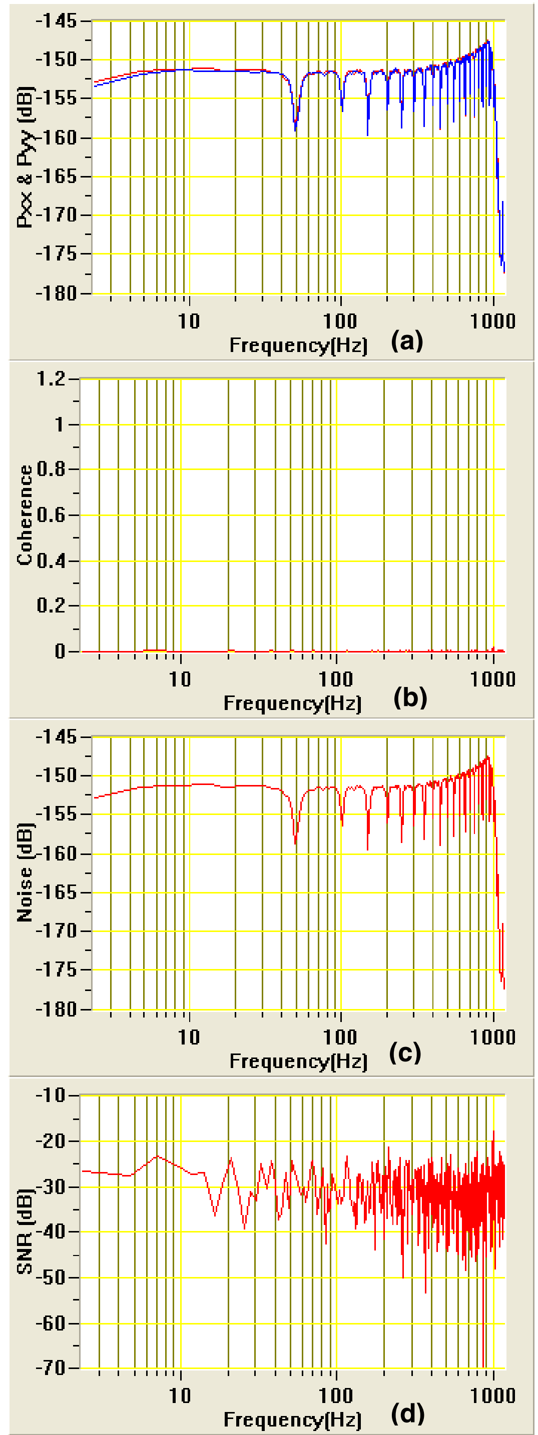
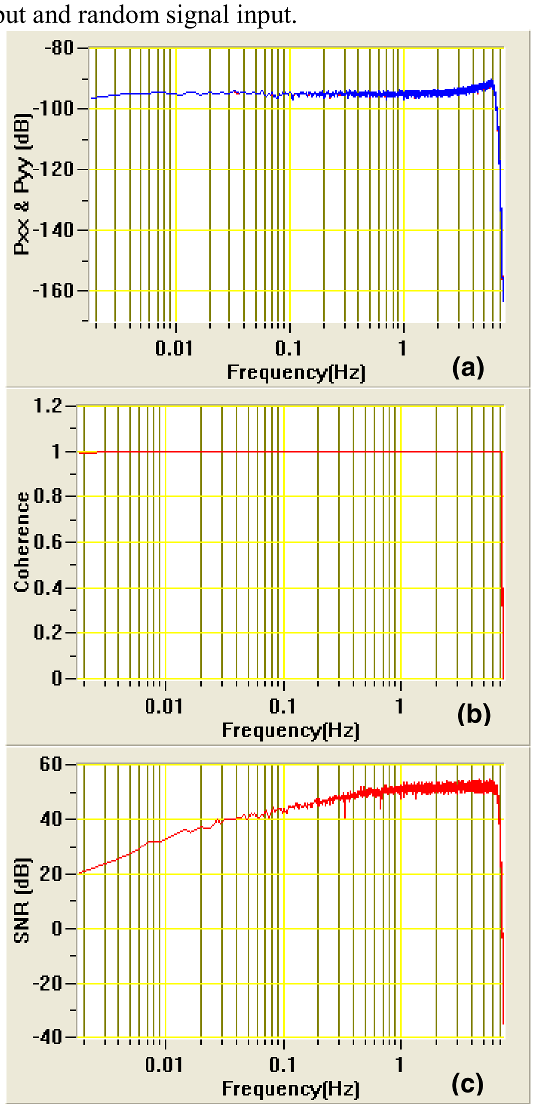



Figure 3. **Short circuited input test result for TS3 time series data (Sample frequency: 2400Hz; (a): auto PSD of Ex (red line) and Ey (blue line); (b): coherence between Ex and Ey; (c): noise PSD between Ex and Ey; (d): SNR between Ex and Ey)**

Figure 2. shows short circuited input testing result of TS4 data. The sample frequency is 150Hz for above time series. Weak coherent interference exist when frequency <2Hz. Figure 3. shows chort circuited input testing result of TS3 data. There is no significant coherent interference in TS3 data. Coherence in Figure 3. (b) and SNR in Figure 3.(d) prove this point.

Figure 4. is random noise input test result for TS5 time series. Compare Figure 4.(a) and Figure 4.(c), it's difficult to find the difference in pass band of channel Ex and Ey. But the SNR in Figure 4.(d) and noise PSD in Figure 4.(b) reveal performance change in pass band of Ex and Ey channel, 1/f noise degrades instrument's SNR when frequency <0.5Hz. Compare Figure 4 (c) with Figure 1. (c), noise PSD in Figure 4. (c) is about 5dB higher than noise PSD in Figure 1.(c). There is minor difference of noise PSD between short circuited input and random signal input.



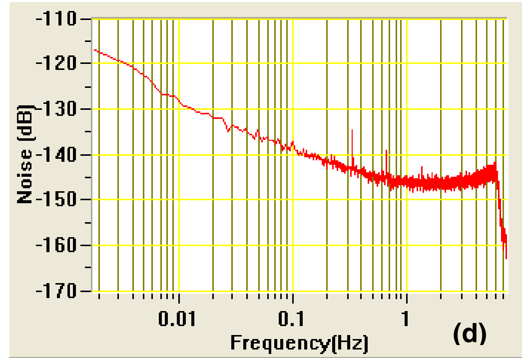




Figure 4. **Random noise input test result for TS5 time series data (Sample frequency: 15Hz; (a): auto PSD of Ex (red line) and Ey (blue line); (b): coherence between Ex and Ey; (c): noise PSD between Ex and Ey; (d): SNR between Ex and Ey)**

## 6. Conclusion and discussion

Random noise and coherent interference are major factors determine performance of MT instrument.

Short circuited input test and corresponding spectral analysis can evaluate noise spectrum and coherent interference inside MT instrument. Random signal input test may reveal instrument's noise PSD and SNR for given signal more reliably. Combination of short circuited test and random signal input test offer reliable way to random noise and coherency interference inside MT instrument.

## 7. References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