Jurnal Sains dan Matematik Vol.3 No.1 (2011) 50-55
ISSN 1985-7918

Development of a Low Frequency Noise Measurement Setup

Pembangunan Alat Pengukuran Hingar Frekuensi Rendah

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Abstract

Low-frequency noise measurement is a scientific technique which is capable of probing down to localized microscopic phenomena of electron devices. It can be used as a diagnostic tool in application concerning the reliability of electron devices. In this research, a low-frequency noise measurement (LFNM) setup to measure $1/f$ noise is designed, developed and validated. The measurement setup consists of a biasing circuit, a transimpedance amplifier and a dynamic signal analyzer. Two metal boxes were used to shield the setup from signal interference. A LabView-based program is developed to extract the noise power spectral density data from the dynamic signal analyzer for further analysis. Validation of the measurement setup was made by measuring the thermal noise of two standard resistors. The obtained results were similar to the theoretical values.

Keywords low-frequency noise measurement, 1/f noise, noise power spectral density

Abstrak

Pengukuran hingar frequensi rendah adalah satu teknik saintifik yang berkeupayaan untuk menyiasat hingga ke fenomena mikroskopik sesuatu peranti elektron. Ia boleh digunakan sebagai alat diagnostik dalam aplikasi berkaitan kebolehpercayaan peranti-peranti elektron. Dalam projek ini, sebuah peralatan pengukuran hingar frekuensi rendah untuk mengukur hingar $1/f$ dalam bahan-bahan nanokomposit telah di rekabentuk dan dibangunkan. Peralatan pengukuran ini terdiri daripada sebuah litar bias, penguat transimpedan dan penganalisis isyarat dinamik. Dua kotak logam digunakan bagi melindungi peralatan pengukuran dari gangguan isyarat luar. Sebuah program berasaskan LabView dibangunkan untuk mengawal dan mendapatkan data ketumpatan spektra hingar daripada penganalisis isyarat dinamik. Validasi peralatan yang dibangunkan ini di buat dengan mengukur hingar terma dua perintang piawai. Hasil yang diperolehi adalah setara dengan nilai teori.)

Katakunci pengukuran hingar frekuensi rendah, hingar $1/f$, ketumpatan spektra kuasa hingar

Introduction

Noise is a random fluctuation of electrical quantities which changes unpredictably over time. There are various types of noise exist in electron devices such as thermal noise, shot noise, generation-recombination (G-R) noise, and $1/f$ noise. Thermal noise and shot noise, both independent of frequency, are inherent in electron devices with the former is caused by random thermally excited fluctuation of charge carriers in a conductor. The latter is associated with current flow across a potential barrier. Contradicted to the above, the G-R and $1/f$ noises are frequency dependent and are due to device quality. Their occurrence are mainly in the lower part of the frequency spectrum. The origin of G-R noise is related to the fluctuation of the number of free carriers caused by the presence of G-R centres in the semiconductor material and/or its interface. On the other hand, $1/f$ noise is influenced by the presence of localized defects and irregularities in the microstructure of electron devices (Ciofi, 2000)**.**

The first observations of $1/f$ noise were made in 1925 when J.B. Johnson discovered, in a thermionic tube, a noise whose spectral density decreased with increasing frequency. He proposed that this excess noise was due to the fluctuations in the work-function of the cathode surface due to particle migration. A year later, Schottky suggested that this noise arises from slow random changes of the thermocathode's surface, and given the name "Fackelneffekt" ("flicker effect") or "flicker noise" (Kogan, 1996). Since then, and drastically after the World War II, measurements of the low frequency noise spectra in electronic materials and devices have been performed on a vast number of samples, such as in semiconductors e.g. Germanium (McWorther, 1957), amorphous silicon (Gunes *et al*., 1999), in metals and contacts (Hooge, *et al*., 1981), on devices such as Schottky diodes (Hsu, 1970), *pn* diodes (Kleinpenning, 1985), laser diodes (Jang, 1983), MOSFETs (Butler and Hsiang, 1987) bipolar transistors (Sanchez and Bosnan, 2000) thin film transistors (Rhayem et. al.1998), and quite recently in organic thin film transistors (Martin et al., 2000), dielectric materials (Rychetsky et al., 2003), and in nanostructure materials (Aveek, 2005; Smeets, 2009).

Low-frequency noise data are useful for estimation of device quality and reliability analysis according to the fact that low frequency noise is sensitive to hidden device defects and degradation processes. Due to that factors, research in low-frequency noise measurement of electron devices have been widely undertaken by researchers throughout the world. The purpose of this paper is to explain the development of a low-frequency noise measurement setup which, in future, will be used to investigate the noise in nanocomposite materials devices.

Research Methodology

Different low frequency noise measurement setups are used in practice, but some common features were found in all cases. The basic requirements for any low frequency noise measurement system are

1. biasing circuit,
2. amplifier system with high gain and very low background noise,
3. spectrum analyser with suitable dynamic range and bandwidth to cover the frequency range of interest, and
4. shielding to avoid influence of external interference.

In this work, the low-frequency noise measurement setup was designed to measure low-frequency electrical noise in a two terminal device in the frequency range of dc to 1000 Hz.

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It consists of a low noise biasing circuit powered by batteries, a device-under-test (DUT), an ultra-low noise transimpedance amplifier (ULNA, Signal Recovery 5182), a dynamic signal analyser (DSA, Agilent 35670A) and a personal computer as schematically presented in Figure 1. Since it is a wide frequency range measurement, dc to 51.2 kHz, the measurements were taken in several parts. Averaging is needed in this type of measurement. In this work, averaging by 100 times in rms mode is found sufficient in order to obtain a meaningful result. A LabView-based program is developed to retrieve the noise power spectral density data from the DSA. Two metal shield boxes were used to protect the DUT and the transimpedance amplifier from low-frequency signal interference. Validation of the setup was made by measuring the thermal noise of two standard resistors.

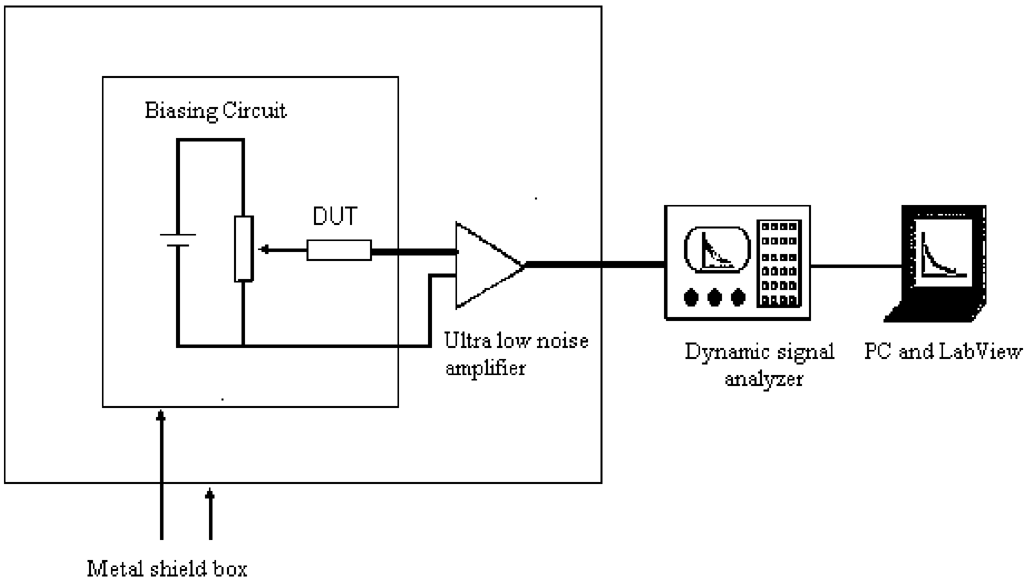

Figure 1 Schematic diagram of the experimental setup for noise measurement

Results

In any low-frequency noise measurement, the first thing to do is to measure the system noise or background noise. Figure 2 shows the background noise of dynamic signal amplifier (DSA) and transimpedance amplifier at three gain settings (10^{-6} A/V, 10^{-7} A/V and 10^{-8} A/V). As can be seen, the background noise of the dynamic signal analyser is very small which is well below the background noise of the transimpedance amplifier. These data gave us a confirmation that the two devices can be used to measure a low-frequency noise.

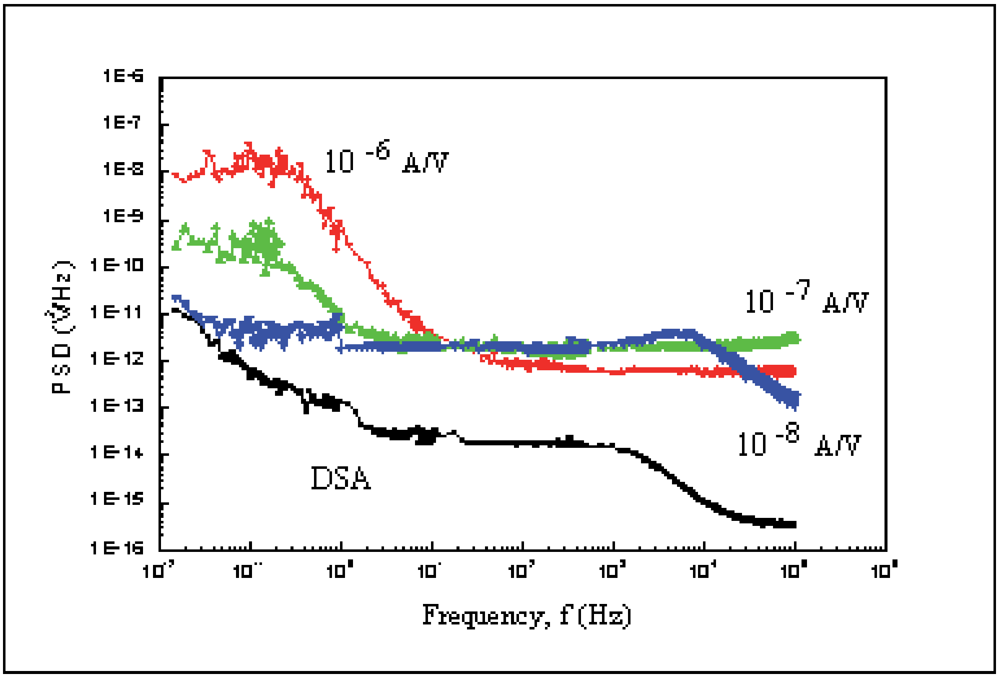

Figure 2 Background voltage noise power spectral density of transimpedance amplifier and dynamic signal analyzer.

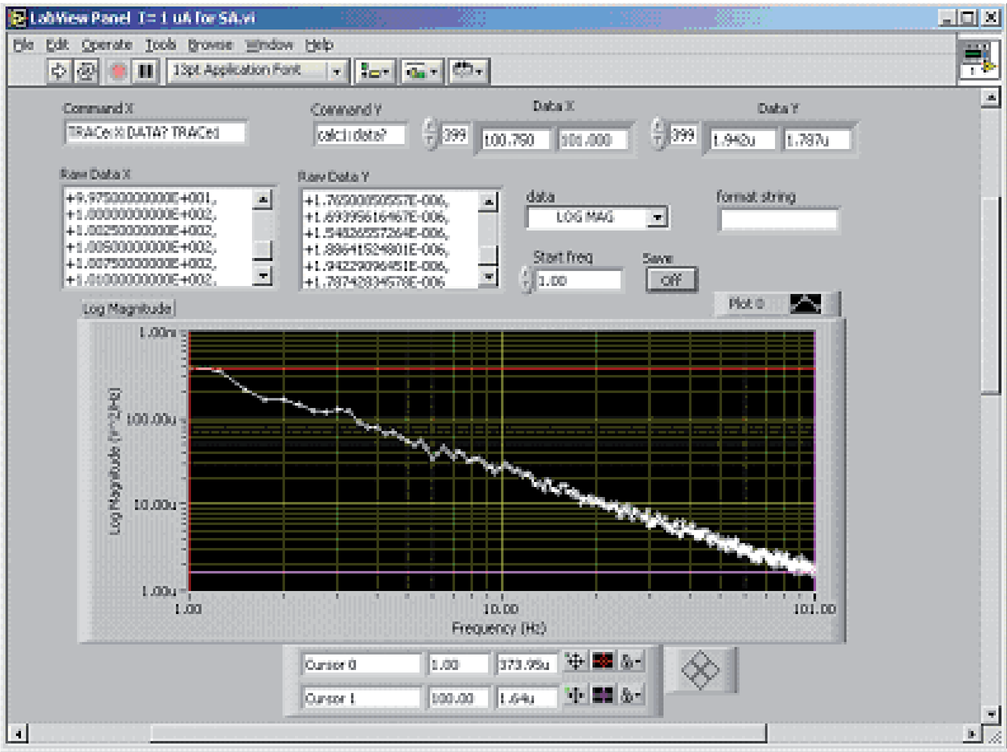

Figure 3 LabView panel window for acquiring PSDs data.

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ISSN 1985-7918

A custom-made program was developed within the LabView software environment for acquiring the noise power spectral density data from the dynamic signal analyser via the HPIB bus by a personal computer. Figure 3 shows the LabView front window panel. Validation of the measurement setup was done by measuring the standard resistor of 5MΩ and 10MΩ. Figure 4 shows the thermal noise power spectral density of the two validating resistors (5 MΩ & 10 MΩ) and transimpedance amplifier (LNA) at its highest gain (10^{-8} A/V) and lowest noise (LN) . It can be seen from the figure, the average current noise power spectral density (PSD) of the two resistors in the frequency range of up to 1kHz are similar to the theoretical values.

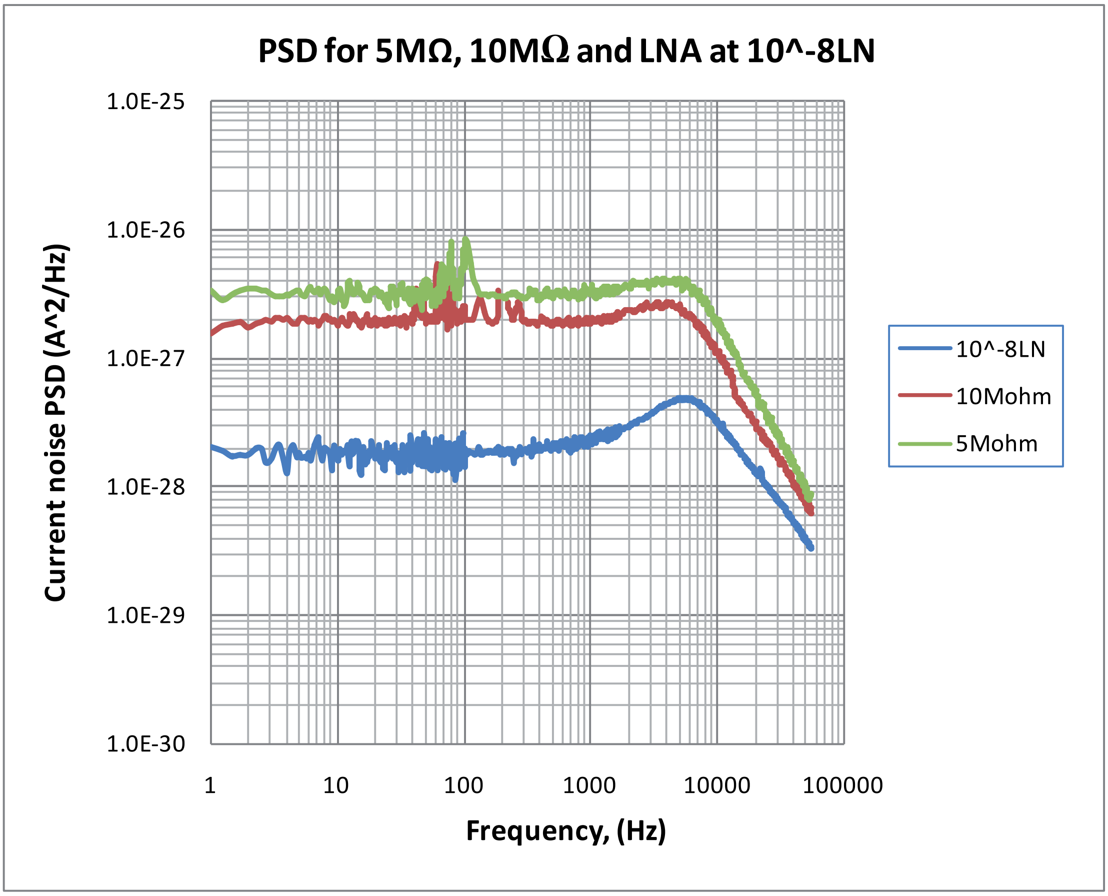

Figure 4 Validation of the measurement setup.

Conclusion

The low-frequency noise measurement (LFNM) setup has been designed, developed and validated. The validation was performed by measuring the thermal noise power spectral density of two standard resistors. The obtained results were comparable to the theoretical values. The setup is now ready to be used as a diagnostic tool in investigating low-frequency noise phenomena in any two-terminal electron devices.

Acknowledgments

This work is supported by Ministry of Higher Education Malaysia under research grant FRGS/ KPT 04-02-05-07. We also like to thank Bysr Ahmad and Syahir Shamsuddin for fabricating the metal shield boxes.

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