APPLICATION BRIEF

A Low-Distortion AC Current Source for Harmonic Hall Applications

In conventional Hall effect measurements, the Lorentz force acts on flowing charge giving rise to a potential difference across a conductor or semiconductor. This so-called Hall voltage is mutually orthogonal to both the direction of current flow in the material and a component of an external or internal magnetic field. The Hall effect measurement has become a standard approach for characterizing carrier type, mobility, and carrier density in semiconductors. In recent years, harmonic Hall effect techniques have emerged to study a variety of physical phenomena including spin-orbit torque interactions in a metal-magnetic[1] and van der Waal[2] heterostructures. For harmonic Hall measurements, an AC current is sourced at a frequency, ω, and the first and second harmonic responses of the Hall voltage are analyzed to extract key physical parameters. As an example, in a spin-orbit torque (SOT) measurement the second harmonic Hall voltage is used to separate damping-like and field-like torques in the material.

In harmonic Hall applications, measurement results are susceptible to harmonic distortion in the current source. In this case, harmonic distortion refers to the presence of frequency components in the output of a current source that are integer multiples of the fundamental frequency of the desired drive current. This occurs when the current source exhibits nonlinear behavior — causing deviations from a purely sinusoidal waveform. In harmonic Hall measurements, higher-order harmonics of the driving current can couple into the second and third harmonic Hall voltage signals through mechanisms such as the ordinary Hall effect. These contributions often manifest as offsets, which must be carefully identified and removed — either manually or through fitting procedures — during data analysis. In spin-orbit torque (SOT) samples exhibiting strong magnetoresistance, spurious harmonic drive currents can lead to artifacts which mimic genuine torque signals unrelated to spin-orbit interactions, potentially leading to misinterpretation of the extracted torque components.

Lake Shore CRYOTRONICS

In this work, the harmonic distortion of two research grade current sources is compared. A 7 mA RMS current from each source is passed through a 25 Ω, 1 W power resistor. The resistor is mounted on an additional heat sink to limit higher harmonic signals arising from self-heating in the resistor. The magnitude of the first harmonic voltage across the resistor is measured, as a function of frequency, with a Stanford Research 830 lock-in amplifier which is frequency locked to the reference out of the respective current source. The second harmonic voltage is then acquired using the same frequency sweep parameters as used with the first harmonic voltage. Here, the degree of harmonic distortion of the second harmonic, $HD_{2\omega}$, is defined as:

$$HD_{2\omega} = 20\,log\left(\frac{V_{2\omega}}{V_{\omega}}\right)$$

where $V_{2\omega}$ is the RMS magnitude of the second harmonic voltage and V_{ω} is the RMS magnitude of the voltage at the fundamental frequency. The results of these measurements are shown in Figure 1.

From Figure 1, the BCS-10 balanced current source offers significantly smaller harmonic distortion at frequencies below 200 Hz where many harmonic Hall measurements are carried out. The linearity of the BCS-10 output stage is the key to achieving a low-distortion sinusoidal current. The BCS-10 is part of the M81-SSM Synchronous Source Measure platform and can be paired with multiple voltage measurement modules for a complete harmonic Hall solution[3] (Figure 2).

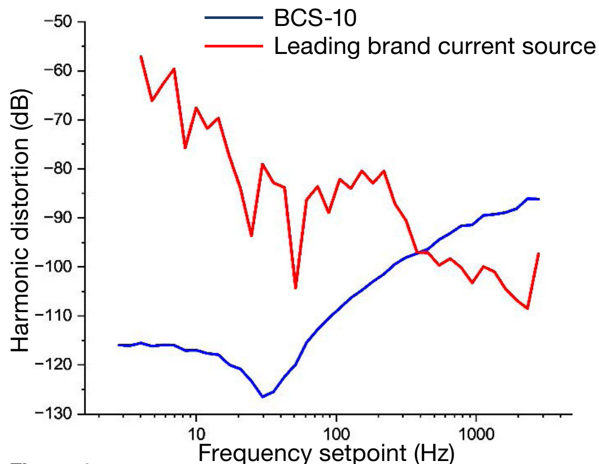

Figure 1
Comparing the Harmonic distortion of an M81-SSM BCS-10 and the industry-leading AC current source used in many harmonic Hall measurements.[2]

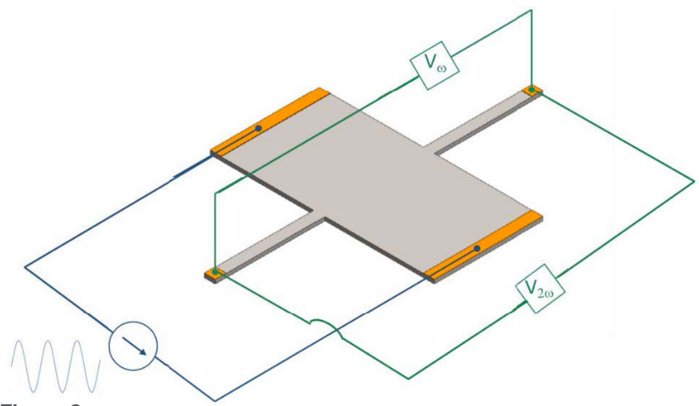

Figure 2
Recommended configuration for a harmonic Hall measurement using the M81-SSM platform. Here a BCS-10 provides a low-distortion sinusoidal current, and two VM-10 modules are used to synchronously detect the first and second harmonics of the Hall voltage. Measuring both $V_{2\omega}$ and V_{ω} at the same time decreases the systematic error in the measurements due to drift as well as reducing the overall time of lock-in measurement.

Conclusion

Harmonic distortion introduces measurement artifacts that compromise the accuracy of harmonic Hall and spin-orbit torque experiments. For these applications, the M81-SSM BCS-10 offers low harmonic distortion, enabling improved detection of the harmonic voltages in these challenging applications.

References

1. *K. Garello, I. Miron, et al., "Symmetry and magnitude of spin–orbit torques in ferromagnetic heterostructures," Nature Nanotechnology, vol. 8, no. 8, p. 587, 2013.*
2. *X. Wang, J. Tang, et al., "Current-driven magnetization switching in a van der Waals ferromagnet Fe_3GeTe_2," Science Advances, vol. 5, no. 8, p. eaaw8904, 2019.*
3. *G. S. Choi, S. Park, et al., "Highly Efficient Room-Temperature Spin-Orbit-Torque Switching in a Van der Waals Heterostructure of Topological Insulator and Ferromagnet," Advanced Science, vol. 11, no. 21, p. 2400893, 2024.*