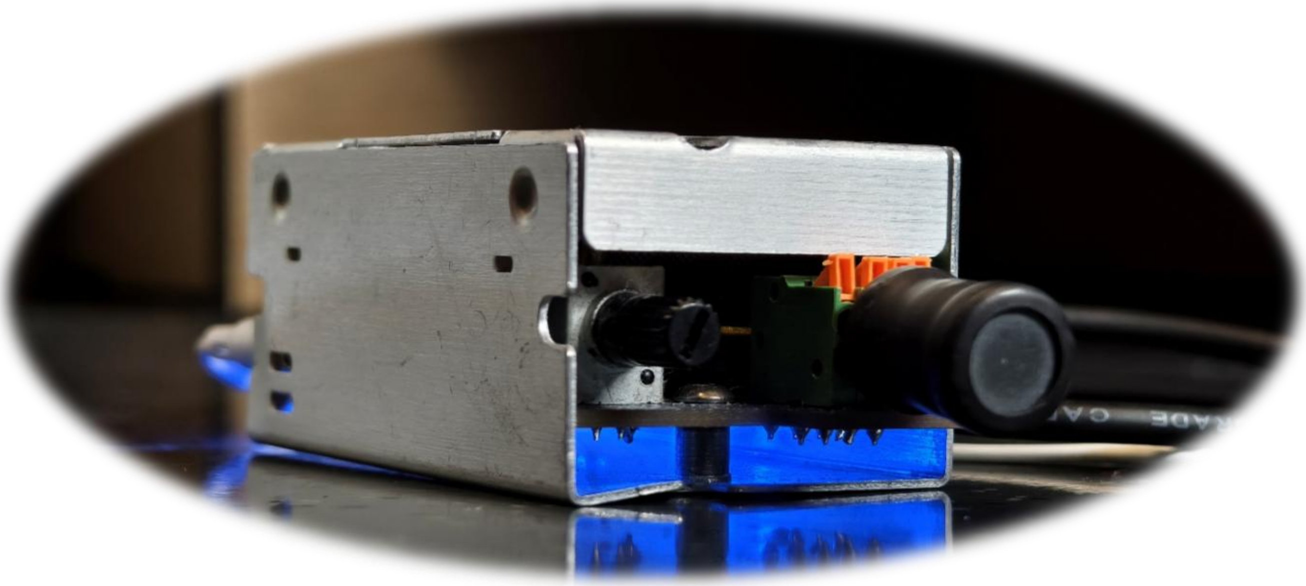

Electromagnetic Recording Technology and Analysis for 3-Phase AC Motor

Technical Blue Book

Rev 1.1

SunnTV/Primary Author

Edition Date：2025.7.21

Preface

I. History of Development

Electromagnetic Recording of Motor and Its Analysis Technology (Mo-Ha Inductor Technology) is an emerging research direction targeting the research, development, and accurate analysis of motors and their actuating systems. The sound wave file that the Mo-Ha inductor recorded is called “Mo-Ha radio”, which has attracted some railfans with its accurate, clear and distinctive listening experience.

Its early development history has a unique evolutionary trajectory. This technology was first invented by Japanese researchers before 2013. However, due to factors such as the lack of historical data, the exact time of invention, the inventor(s), and the source of the original technical literature remain unclear. Owing to insufficient channels for dissemination and popularization, it was discontinued in 2017. Before 2018, the group of people who mastered Mo-Ha Inductor was limited to Japanese railfans.

In 2018，The technology ushered in a crucial turning point in its dissemination and development in China. The first investigative article of the Mo-Ha Inductor in China was released on 07 Oct 2018, written by "加特技の肖特基"(Bilibili UID: 220243). He introduced the Mo-Ha Inductor into China through technical sharing and practical exploration. He also presented his self-made designed circuit. "大糖果 2"(Bilibili UID: 302380924) integrated domestic practical needs, carried out preliminary optimization of the original technology, and released a 1st Generation prototype of the Mo-Ha Inductor in 2021, using it to complete recording attempts on Shanghai Metro trains and China Railway high-speed trains. He made adjustments in aspects such as circuit structure design and component selection, making the technology more suitable for domestic application scenarios and laying the foundation for subsequent development. A user stands as one of the earliest pioneers in China who utilized Mo-Ha Inductors for electromagnetic recording of motor sounds, being among the first batch to engage in such recording endeavors.

In early 2023, technological development entered a new phase. Industry insiders such as "Chen-Leigang" (Bilibili UID: 673977755. Known as CLG below.) and "bulbtester2009" (Bilibili UID: 3461563962886453. Known as BT09 below.) further deepened the technical improvement work based on previous research. They improved the circuit and the placement of components, such as converting the external battery to an internal one, to avoid damage caused by pulling and stretching the wires during transportation or frequent handling, thereby enhancing the durability of the equipment. In the same year, the CLG C2.1 type Mo-Ha Inductor, integrating the above functions, was mass-produced, providing a sample support for subsequent product iterations.

In August 2023, the first CLG C2.3 model Mo-Ha Inductor was born in Guangzhou. With its cheapness and variable agent factories, this model became the most sold model in the institute's archive records and at the time of the release of this document, at least 200 copies (with derivations) had been sold. This model introduced the spring terminal of the inductance coil for the first time, improving the reliability of the Mo-Ha Inductor. Meanwhile, the first solutions of increasing amplification came out. Lowering one of the resistors is an example. However, due to the limitations of the circuit conditions, this solution was not reliable because the operational amplifier is prone to overload with too low resistance, which seriously affects the reception.

At the end of 2023, a discussion QQ group for magnetic pickups was established, marking a shift from the scattered exploration by the public to organized development and research, providing a core support for technical standards and iterations. In early 2024, the Mo-Ha Radio Research Institute and the purchase and technical exchange groups were officially established, standardizing the channels for magnetic pickup transactions and exchanges.

2024 marks the year when Mo-Ha Inductor technology became popular in China. BT09 pushed the boundaries of the 1st generation circuit technology and successfully released the first high-magnification model B2.5. It firstly reached the 26x amplification limit within the framework of the first-generation circuit while fully retaining the performance redundancy of the operational amplifier. At the same time, the power switch was changed from a self-locking switch to a toggle switch, further reducing the failure rate. In the transition from spring to summer, the first circuit iteration was launched, introducing the second-generation circuit. The first model was the C2.9 type released by CLG in May of the same year. However, due to high failure rate, it didn’t made into mass production, there were 9 copies in the trial batch. The first model which made 2nd Generation famous and practical is SY01 series. Compared to the first generation, the second-generation circuit achieved higher magnification, widely adopted stacked operational amplifiers to enhance practicality, and integrated lithium batteries and charge/discharge control functions (which later became standard). Meanwhile, AA batteries and CR2032 are used for power supply. These breakthroughs led to a significant increase in users, bringing Mo-Ha Inductors into the view of railfans and accelerating the popularization of the technology.

In April 2025, @某地铁迷_(Bilibili UID: 349435618499235) introduced the cascaded dual operational amplifier for the first time and launched the M2 series, which is the model with the strongest 1st Generation circuit performance. It comes with built-in hardware high-pass and low-pass filters and a higher amplification factor (up to 2601x).

In June, the official website of the Mo-Ha Radio Research Institute was established, enabling the centralized and authoritative dissemination of the purchase channels for Mo-Ha Inductor technology and related technical materials. This helped with information integration and facilitated efficient access to equipment and resources by enthusiasts, promoting the popularization of the technology and the consolidation of the ecosystem.

Over time, the development of Mo-Ha Inductor has shown multi-dimensional characteristics. In terms of performance improvement, there is a continuous pursuit of higher signal amplification ratios to capture even weaker electromagnetic signals; in terms of energy supply, the lithium battery charging technology is continuously optimized to enhance the device's battery life; the C2L0 model ingeniously utilizes USB devices as power sources, cutting battery consumption; in terms of structural design, efforts are made to optimize the circuit layout and component configuration to achieve miniaturization and portability of the device.

As of now, the Mo-Ha Inductor technology remains in and will remain in the niche hobbyist stage for a long time. The research and manufacturing process (including trial production) is lengthy, and the gray-scale testing period is long. It is extremely difficult to achieve mass production and industrialization on a scale of over a thousand units in the short term. This defect requires more circuit technology enthusiasts or researchers to contribute. Innovation in circuit design and increasing model diversity are needed. Participation in research and manufacturing is necessary to maintain production and meet the growing demand from more and more train running sound enthusiasts.

II. Fundamental Principles

In the realm of technical documentation and professional contexts, the presentation of Mo-Ha Inductor primarily takes two forms: direct connection of various self-made/industrial inductive coils or their parallel connection with amplifier circuits. Among these, the Mo-Ha Inductor based on amplifier circuits is the most widely used in China.

Most of the mainstream Mo-Ha inductors developed in China are based on analog circuits and their working principle is based on electromagnetic induction and leakage magnetic phenomenon. When a train is in motion, electrical equipment such as traction converters generates magnetic fields. Since these devices do not have completely enclosed magnetic circuits, a portion of the magnetic field escapes, known as magnetic flux leakage. The Mo-Ha Inductor typically features a 4-pin socket for the inductive coil to capture these leakage signals. As the alternating magnetic field produced by the traction converter's output passes through the inductive coil via magnetic flux leakage, an electromotive force (EMF) is induced in the coil according to Faraday's Law of Electromagnetic Induction. This EMF is extremely weak and challenging to directly capture or record. To address this, amplifier circuits such as the NE5532 are integrated within the Mo-Ha Inductor. After circuit processing, the induced EMF is amplified by tens or even thousands of times. Some Chinese manufacturers have achieved amplification ratios exceeding 100 times through methods like reducing resistance, enabling recordings in environments with strong electromagnetic interference or from locomotives. The amplified electrical signal is then converted into an audio signal, transmitted via a 3.5mm audio jack to recording devices such as smartphones, ultimately transforming imperceptible electromagnetic variations into audible sounds of train equipment operation. This process enables the electromagnetic induction-based recording of motor sounds during train operation.

There are significant differences in signal essence and physical mechanisms between coil inductive recording and air-conducted mechanical running sounds perceived by human hearing, which are specifically reflected in the following three dimensions.

Signal sources

The core of coil inductive recording is to capture the escaped magnetic flux leakage signals generated by the operation of electrical equipment (such as traction converters) in rail transit vehicles, and these signals originate from magnetic field changes caused by electromagnetic alternations. In contrast, mechanical running sounds stem from air vibrations induced by mechanical movements, including wheel-rail friction, car body vibration, and component operation.

Transmission paths

The former, based on the principle of electromagnetic induction, relies on inductive coils to directly induce magnetic field changes and convert them into electrical signals, without depending on a medium for transmission. The latter, however, requires air as a medium and is transmitted to the human ear through sound wave vibrations, and its transmission process is easily affected by factors such as environmental noise and distance.

Recording targets

Although both serve the monitoring of the operating status of rail transit equipment, the Mo-Ha radio focuses more on the recessive characteristics of electrical systems (e.g., converter modulation frequency, harmonic distribution), while mechanical running sounds mostly reflect the dominant states of mechanical structures (e.g., wheel set wear, abnormal bearing noise). The two construct a "sound profile" of equipment operation from different dimensions, forming functional synergy in fault diagnosis and status evaluation.

III. Analysis of The Recordings

The analysis of Mo-Ha radio aims to extract hidden characteristics of electrical systems (e.g., traction converters) from the captured signals, evaluate their operational status such as asynchronous modulation frequencies and synchronous modulation pulses counts or specific modulations like CHM-PWM, SHE-PWM and SVPWM or more. Sometimes it supports fault diagnosis. This process relies on signal processing techniques and domain knowledge of motor electrical systems, with core dimensions including signal feature extraction, operational state evaluation and fault pre-diagnosis.

In terms of spectrum analysis, software such as Wavetone and Adobe Audition are generally employed. Among them, Wavetone finds extensive application, particularly in its waveform display functionality, while Adobe Audition is only capable of performing preliminary processing.

Asynchronous modulation

For Asynchronous modulation, the analysis primarily relies on the spectrum diagrams generated by Wavetone. Wavetone plays a crucial role in locating the carrier frequency of asynchronous modulation, a task that is fundamental to understanding the dynamic characteristics of the modulation process. As asynchronous modulation is characterized by the absence of a fixed proportional relationship between the carrier frequency and the modulation wave frequency, the carrier frequency itself exhibits variability, and accurately identifying this frequency is key to dissecting the modulation mechanism. Additionally, Wavetone aids in the analysis of the number of cycles in synchronous modulation when combined with auxiliary waveform diagrams.

The spectrum diagram of asynchronous modulation, as presented by Wavetone, reveals distinct features that stem from the non-synchronous nature of the carrier and modulation waves. Unlike synchronous modulation, where the spectrum displays discrete and evenly spaced frequency components with a clear harmonic structure, asynchronous modulation spectra tend to show a broader distribution of frequency components, often with a certain degree of overlapping or diffusion. This smearing effect arises due to the continuous variation in the relative phase between the carrier and modulation waves, leading to the spreading of energy across a range of frequencies rather than being concentrated at specific discrete points.

In Wavetone, the spectrum analysis tools allow for a detailed examination of these frequency distributions. The software can display the amplitude of each frequency component over time, or provide a static view of the overall frequency content within a selected time window. For asynchronous modulation, this enables analysts to track how the carrier frequency shifts as the modulation wave frequency changes, a phenomenon that is inherent to asynchronous operation. The ability to zoom in on specific frequency ranges and measure the intensity of frequency components is particularly valuable here, as it allows for the identification of dominant frequency bands and the detection of any unexpected harmonics or intermodulation products that may indicate anomalies in the motor's electrical system.

Synchronous modulation

In Synchronous modulation especially multi-pulse modes, the carrier ratio (the proportional relationship between carrier frequency and modulation wave frequency) and the modulation ratio (The ratio of the peak amplitude of the modulated wave to the peak amplitude of the carrier wave) is not statically fixed throughout the operation; instead, it features switching points, making wave counting in waveforms a critical means to decode the dynamic adjustment logic of the modulation program. This characteristic—wherein the ratio shifts between an AC cycles(e.g., 7 pulses in a cycle and 5 pulses in the next).

Wave counting for synchronous modulation thus focuses on identifying these subtle transitions rather than tracking a single, unchanging cycle pattern. Using high-resolution waveform tools (such as Adobe Audition, Sonic Visualizer), analysts first isolate stable segments of the signal, typically during the constant-speed phase where modulation adjustments are most pronounced. Within each segment, a "pulse cluster" (a group of carrier pulses corresponding to one modulation wave cycle) is identified, and the number of pulses within the cluster is counted—this number directly corresponds to the current carrier ratio (e.g., 7 pulses indicating 7 pulses division, 5 pulses indicating 5 pulses division). The key to analyzing the synchronous modulation multi pulse mode lies in comparing consecutive pulse clusters: in normal operation, the shift between ratios and pulses (from 7 to 5, for instance) is not abrupt but follows a predefined logic, often aligned with changes in motor load or speed. The transition manifests as a single cycle where the pulse count within the cluster changes, while adjacent frames maintain their respective ratios—this "frame-specific ratio" is the implicit switching point. For example, a segment may show 3 consecutive clusters with 7 pulses each (7th division), followed by 1 cluster with 5 pulses (5th division), then revert to 7-pulse clusters, all without disrupting the overall continuity of the waveform.

These shifts are rarely random, except when train wheel slips. They are programmed to optimize harmonic distribution under varying operating conditions: lower ratios (e.g., 5th) may be used at high loads to reduce switching losses, while higher ratios (e.g., 7th) improve waveform smoothness at light loads. Electromagnetic recordings capture these transitions with exceptional precision, as the pulse clusters retain their internal regularity within each frame (uniform pulse spacing, consistent amplitude) despite the inter-frame ratio changes.

Notably, such switching is often subtle—without high-fidelity electromagnetic recording and detailed wave counting, the shifts would remain obscured. This is why wave counting in synchronous modulation, with a focus on detecting implicit carrier ratio transitions, is central to electromagnetic recording analysis: it uncovers the underlying modulation program’s adaptive mechanisms, revealing how the system balances performance and efficiency through dynamic ratio adjustments.

Synchronous is precisely what electromagnetic recordings aim to reveal, as it reflects the control strategy of the motor actuating system.

IV. Operation Methods

1. Equipment Preparation and Scene Evaluation Before Recording

After the train arrives at the station, comes to a complete stop, and the doors open, operators board the train, carrying coil inductive recording equipment that has undergone power checks (to ensure the battery life of lithium batteries or primary batteries meets the requirements for a single recording) and function tests (coils are undamaged, interfaces are secure).

Upon boarding, priority is given to finding a placement location in the car area corresponding to the traction converter (usually in the middle of the train or under the power car), which must meet three core conditions:

a. Spatial openness: Avoid being blocked by passengers and their luggage or seat backs to ensure the coil can directly face the converter's magnetic flux leakage source.

b. Safety: Stay away from collision-prone positions such as door opening/closing areas and handrail posts to prevent the equipment from slipping or interfering with passenger passage. If it is indeed necessary [to place the equipment in such areas], the Mo-Ha Inductor must be removed when the train doors open.

c. Electromagnetic compatibility: Keep away from strong electromagnetic interference sources such as mobile phone signal boosters, onboard walkie-talkies, and high-voltage busbars to reduce the superimposed interference of environmental noise on magnetic flux leakage signals.

2. Equipment Arrangement and Parameter Configuration

After taking out the Mo-Ha Inductor, three checks and connections must be completed:

a. Hardware integrity check: Inspect whether the 4-pin socket and connecting wires of the inductive coil have breaks or oxidation, and whether the coil windings are neat (loose windings may reduce induction sensitivity). If the train is crowded (especially URBAN TRANSITS), DO NOT place the Mo-Ha inductor on the ground. Change another time to record.

b. Signal link connection: Connect the output terminal of the Mo-Ha Inductor to the input terminal of the recording device (mobile phone, computer, etc.) via a 3.5mm audio cable. A "click" sound should be heard when inserting to ensure full contact of the plug's metal contacts (loosening may cause signal attenuation or disconnection).

c. Placement posture calibration: The Mo-Ha Inductor must be placed horizontally in the correct orientation (with the coil plane perpendicular to the direction of magnetic flux leakage from the converter). Side placement (coil plane parallel to the leakage direction, resulting in halved induction area) or inverted placement (stress on the internal amplifier circuit may cause poor contact) is strictly prohibited, as both directly affect the capture efficiency of magnetic flux leakage signals.

Parameter settings for the recording device must follow the principle of "high fidelity and anti-distortion":

Format selection: Use lossless formats such as WAV (bit rate ≥ 16bit, sampling rate ≥ 44.1kHz), avoiding lossy compression formats like MP3, which may cause loss or distortion of high-frequency signals.

Amplification ratio adjustment: Preset initial values based on the vehicle model (e.g., 50-100x for CRH3A-A trains), and adjust through test recording and monitoring. If the waveform peak exceeds -3dB (per software scale), reduce the ratio to prevent clipping distortion; if the overall waveform is below -30dB, increase the ratio to highlight weak magnetic flux leakage signals.

3. Critical control points of during-recording

When the door closing beep has been over, start recording immediately, to ensure complete capture of the initial modulation signal at the moment the traction converter starts, and some samples for reducing. This is key data for analyzing the converter's startup logic and also facilitates providing noise samples for subsequent noise reduction.

Three dynamic phases require focused attention during recording:

a. Acceleration phase: Keep the equipment stationary. When the train is accelerating, the traction converter is in a frequency-variable modulation state. Moving the equipment will introduce friction noise, which may mask the detailed characteristics of the frequency climb.

b. Constant-speed phase: Monitor signal stability. If sudden spikes, audio pops, ultra-high frequency (e.g. current arc discharge from phase segmentations in AC railways), or silence occur, it may be due to poor equipment contact, short-term protection of the converter, too close to the high-voltage bus cable. If waves exists, the silence often refers to the cut off of output in some traction converters.

c. Deceleration and stopping phase: Continue recording for at least 3 seconds after the train comes to a complete stop. This is because the converter still outputs weak standby signals after braking ends; extending the recording period ensures complete capture of the full-cycle electromagnetic characteristics of the "start-up - operation - stop" process.

4. Prohibited Scenarios and Interference Avoidance

It is generally not recommended to place the Mo-Ha Inductor outside the vehicle or near overhead line poles with a voltage of 15kV or higher for recording. Oersted's experiment demonstrates that magnetic fields exist around energized conductors, similar to those around permanent magnets. Due to the high voltage of overhead lines, the interference noise from trackside equipment is mainly composed of 50 or 60Hz and its harmonics, resulting in a low signal-to-noise ratio and a large amount of ineffective harmonics, which are difficult to remove in post-processing. Additionally, when recording outside the vehicle, the magnetic flux leakage signals are weak and lack continuity, as the traction leakage magnetic field is already overwhelmed by significant interference.

5. After-Recording Processes

After importing the recording to a computer, a three-step processing method of "noise reduction-gain adjustment-editing" is adopted:

For Audio

Noise elimination: In Adobe Audition, select a pure noise segment (approximately 1-2 seconds) recorded after the train has come to a complete stop as the noise sample. Use the "Effects > Noise Reduction/Restoration > Noise Reduction (Process)" function to remove ambient base noise with a noise reduction intensity of 30-50%.

Signal equalization: Use a hard limiter tool to control the peak amplitude within -6dB. Meanwhile, enhance the 200-5000Hz frequency band (the main modulation frequency range of the converter) through multi-band EQ, and weaken high-frequency interference above 10kHz.

Segment screening: Retain complete signals from the acceleration, constant-speed, and deceleration phases, and discard segments with equipment movement or sudden interference, or too-long recordings without variations (e.g. cruising speed) to save storage space and blending time. Export the file in a format compatible with the video project (e.g., a WAV file with a 48kHz sampling rate, at least 16-bit depth). Specific editing schemes will not be elaborated here.

For Video

Signal Visualization and Recording:

After noise reduction, use Wavetone or Sonic Visualizer to generate spectrum graphs and record the rolling playback of these visuals while capturing the full audio. Simultaneously, output waveforms using tools like Corrscope to obtain dynamic waveform displays.

Material Integration in Editing Software:

Import the recorded spectrum videos, waveform visuals, and reduced audio into editing software. Align the time axes of all materials to ensure synchronization between audio playback and visual changes, then trim redundant segments to streamline the content.

Enhancement and Publishing:

Add text annotations. In the start of the video, the text often includes recording section (usually between two stations, or a complete acceleration and deacceleration), consist number, and recording carriage. During the Mo-Ha radio, the most necessary text is the modulation analysis in a specific section, which is the most valuable information. Once finalized, export the video in a suitable format and publish it with a cover of the train picture.

WARNING!

If questioned by on-board staff during recording, cooperate with their necessary equipment inspections and immediately state that the purpose of the recording is "personal hobby research on train motor sounds". If it is necessary to disassemble the device, comply with the user terms provided by the Mo-Ha inductor manufacturer to avoid unnecessary misunderstandings or troubles.

During the recording process, it is *strictly prohibited* to touch live train equipment or interfere with the normal operation of the train.

Changelog [en-us]

Rev 1.2 – 25 Jul 2025 05:50 UTC

Correction:
1. Corrected known spelling error(s), including the cover page.
2. Corrected known knowledge-based errors and ambiguous expressions.
Adds:
1. Added key milestones of the Mo-Ha Inductor Research Institute and some new developers and iconic products to Chapter I.
II. Added necessary information.

Rev 1.1 For en-us Version – 21 Jul 2025 17:00 UTC

Correction:
1. Title translation changes: *Electromagnetic Recording Technology and Analysis For 3-Phase AC Motor*.
2. Some typing formations for branch contents.
3. Corrected known spelling error(s), including the cover page.
4. Make some necessary abbreviations to make it easier to read.
Adds:
1. Added a new chapter III mainly talked about analysis.
2. Added Some words to explain distinctly.

Rev 1.0 – 19 Jul 2025 16:43 UTC

Electromagnetic Recording of Motor and Its Analysis Technology Blue Book is the first article on Mo-Ha Inductor technology and application technology published by the Mo-Ha Inductor Research Institute (Rev 1.0), first released on July 18, 2025 UTC. Relying on the experience of the institute's members, it systematically summarizes and compiles the entire chain of Mo-Ha Inductor technology from its origin to principle and operation.