Analysis of Ribbon Microphone Output Transformers and their Influence on the Microphone´s Sound

Prof. Dr.-Ing. Dieter Leckschat[1], Dipl.-Ing. Julian David[1,2]

[1] *Department of Media, Düsseldorf University of Applied Sciences, 40474 Düsseldorf, E-Mail: dieter.leckschat@fh-duesseldorf.de*

[2] *Audio Engineering Associates, Pasadena, California, E-Mail: info@soundphile.de*

Introduction

Ribbon microphones have come a long way from their historical roots in the 1930s. While they became somewhat out of fashion during the years of magnetic tape recording, the age of digital recording has led to a renaissance of the ribbon microphone. Apart from the acoustic design, the transformer is thought to be the most important component of any passive ribbon microphone in terms of its influence on the sound quality. However, many engineers and home recordists apparently have little to no knowledge about the basic concepts of transformers, which leads to dubious forum discussions fueled by esoteric half-truths and audio myths. Often times it's a matter of trial and error whether replacing the transformer actually turns out to change the sound of the microphone in the desired way. Very little scientific data comparing current ribbon microphone transformers can be found. Although there have been previous publications dealing with transformers in ribbon microphones, none of them thoroughly describes the transmission system consisting of ribbon transducer, transformer and load impedances, and explains the interaction of their complex impedances. Thus, it appears that a fresh look at some basic concepts and the role of the transformer in ribbon microphones is appropriate to remedy this situation.

Ribbon microphone technology

Ribbon microphones are electrodynamic transducers with an aluminum ribbon loosely suspended in a magnetic field. As sound waves impinge on the transducer, the pressure differences between the front and the back of the ribbon cause it to vibrate. The delivered output voltage is proportional to the velocity of the ribbon vibration as shown by the electrodynamic transduction principle.

$$\begin{pmatrix} U \\ I \end{pmatrix} = \begin{pmatrix} 0 & M \\ 1/M & 0 \end{pmatrix} \begin{pmatrix} F \\ v \end{pmatrix} \tag{1}$$

$$U = B \cdot l \cdot v \quad \text{[V]} \tag{2}$$

With the voltage U, the current I, the force F, the velocity v, the magnetic flux density B, the conductor length l and the transduction constant M.

Passive ribbon microphones require an output transformer in order to step up the voltage and deliver an appropriate output level. Figure 1 shows a simplified equivalent electromechanical circuit of a ribbon microphone.

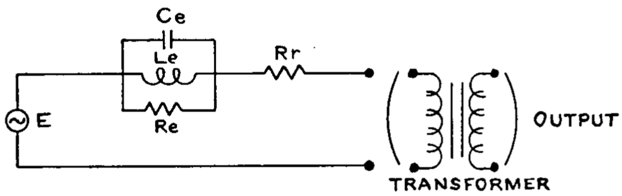

Figure 1: Equivalent electromechanical circuit of a ribbon microphone

The mechanical resonance of the ribbon is tuned to be at the low end of the audio spectrum. Above resonance, the impedance of the ribbon is mass-controlled. The electrical impedance of the ribbon is a function of frequency and approaches a magnitude of up to five times its DC resistance at resonance depending on the ribbon motor design. The transmission system of a passive ribbon microphone consists of the ribbon motor, the transformer and the load impedance of a preamplifier. Each of these elements has a complex impedance that interacts with the others because transformers will reflect impedances by the square of their voltage ratio.

Test setup

A test jig was developed to allow electrical measurements to be performed on a variety of ribbon microphone transformers. This test jig was comprised of a source network mimicking the ribbon motor impedance, a transformer under test and different load impedances ranging from 250 Ω to 35 kΩ including two preamps. Electrical measurements were performed using an Audio Precision System 2722 and consisted of a wide range of nonlinear distortion measurements, amplitude and phase frequency response, and group delay. In addition, the frequency response measurements were also performed electroacoustically using a Monkey Forest rig in the University's anechoic room.

Measurement results

All the transformers exhibit a second-order filter behavior at both the low and the high frequency extremes. At the low end, the filter is formed by the source impedance reactance and the primary inductance of the transformer. Figure 2 shows this behavior for different source impedances and two selected transformers with a load impedance of 10 kΩ.

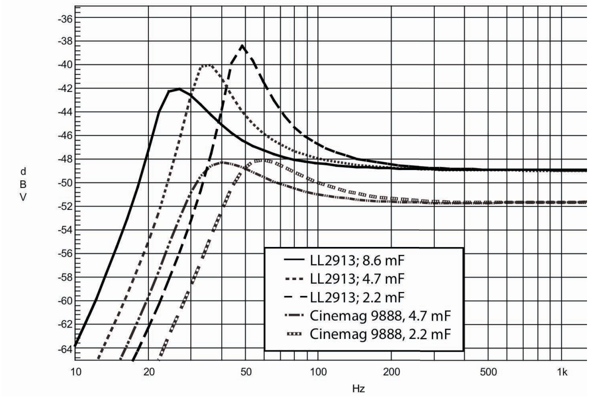

Figure 2: Variations in Frequency Response for different combinations of source impedance and transformer

Although this behavior has previously been described by Gayford, its significance for its application in ribbon microphone transformers has not yet been discussed. The load impedance considerably affects the frequency response, microphone sensitivity, and thus the system's signal-to-noise ratio. The load impedance effectively controls the resonance of the second-order filters. Thus, insufficient load impedances will lead to decreased bandwidth, whereas too high of a load may allow transformer ringing and inferior time domain behavior. Various harmonic, intermodulation (according to SMPTE and CCIF), and dynamic intermodulation distortion (DIM) measurements were performed to analyze the nonlinear distortion behavior of the transformers. The measurements reveal significant differences in nonlinear distortion performance among the tested transformers. These differences are most obvious at low frequencies, where transformers run into saturation. Here, THD (total harmonic distortion) differences of up to 40 dB can be observed. The electroacoustical measurements support the differences found in the frequency domain and also prove the validity of the test jig simulating the ribbon microphone's source impedance.

Listening test setup

A listening test that included musical sounds was carried out with a small number of expert listeners in order to show correlations between measured electroacoustical parameters and listener judgments. The hypotheses for the listening test were based on the indications of the measurements. These were:

- There is an audible difference between a measurement-wise „good" and a „bad" transformer attributable to harmonic distortion.
- There is an audible difference between two selected transformers attributable to different bass responses.

The musical sounds chosen as excitation signals were:

- Two organ tones produced by separate loudspeakers, playing a short melody
- A drum loop featuring strong transients as well as low-frequency content
- A pure 60 Hz sine tone

Thirteen experienced listeners took part in the listening test and were exposed to A-B-A-B comparisons of short sound samples. The test analyzed the judgment confidence of the listening jury by identity and repetition tests.

Subjective results

The statistical significance of the listening test results strongly depended on the different musical sounds and the hypotheses to be tested. When asked to evaluate the audible differences with regards to distortion for the drum loop, the listeners judged these differences (if any) to be extremely subtle and without statistical significance. Only 23% of the listeners were able to identify repetitions and only 38% judged identical examples as such. Better (i.e. more significant) results could be achieved with the organ and sine wave tones. For the sine wave, the perception thresholds were noticed to be in the same range known from previous literature. For musical signals, no statistical proof for the perception of differences between transformers could be found. Asking for audible differences with regards to frequency response, better consistency was achieved. Here, 54% of the listeners judged repetitions correctly and 69% voted for one transformer to have a more accentuated, heavier sound.

Summary

In this research, an equivalent electromechanical circuit for a ribbon microphone has been set up and a test jig has been built to measure transformer behavior. Furthermore, the importance of source-transformer-load impedances has been worked out. It was discovered that the interaction of these complex source impedances had not been thoroughly discussed in common literature. Linear and nonlinear distortion has been measured and considerable differences were found between different transformers. Listening tests with a small number of experienced listeners were carried out showing that reliable subjective evaluation is difficult to achieve. However, a revised test setup and refined test questions could reveal a better correlation with the measurement results. A more in-depth report on the research will be published in an AES paper at the 128th AES Convention in London in May 2010.

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