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Acoustic simulation of mobile phone coupled to artificial ear

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ABSTRACT

Artificial ear is being used to evaluate the acoustic response and the sound quality of the mobile telephony devices, which simulates the practical listening condition of the outer ears. In this paper, a method to estimate the coupled acoustic response of the device with an artificial ear is studied to be effectively used in the design. To this end, an equivalent circuit model of the total receiver system including all accessory elements is established. Acoustic impedance of artificial ear, which is essential in the equivalent model, is directly measured by using three microphones arranged in tandem on the duct wall connected to the artificial ear. Input impedances of two artificial ears, Type 3.3 and 3.4, which are currently employed as the standard devices, are measured. The measured data is incorporated into the model to predict the acoustic response. To validate the proposed model using the measured impedance, the measured acoustic responses of two simulation systems including mobile phone and artificial ear are compared with the predicted ones. A reasonably good agreement between measurement and prediction is observed, and their difference is less than 4.5 dB at the narrow communication band for a mobile phone ($f < 3.4$ kHz). It is also found that the input impedance of Type 3.3 ear is more robust to the change of measuring condition than Type 3.4 ear.

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1. Introduction

In the acoustical design of a handset type audio-visual (AV) telephony device, an artificial ear is used to simulate the acoustic performance in the actual hand-held usage condition in contact with an ear. Artificial ears, Type 3.3 and 3.4, are currently used as the standard test rigs in telecommunication industries. The acoustic response of such telephony device is measured at the *drum reference point* (DRP) and converted to the response at the *ear reference point* (ERP) by using the calibration table specified in the ITU-T P.57 [1]. The measured acoustic response of the sample is to be compared with the desired preset performance. The foregoing experimental procedure is repeated in a trial-and-error way until the desired response is reached by modifying design parameters.

There have been several virtual design approaches for the compact acoustic system of the mobile phone. Automatic design method [2] was proposed to improve the degraded sensitivity caused by the leakage of the coupler, i.e., so-called pseudo ear, according to the IEC-60318 standard. They tried to optimize the design parameter and structure of the derived electric circuit model by using the genetic algorithm. The same method was applied to the automatic design of an artificial ear Type 3.2 to fit the receiver response in the *global system for mobile* (GSM) specification [3]. However, the comparison of the automatic design method with the experimental ones was not shown for both cases.

To understand the performance of simulators as representing the average human ear, ITU-T Study Group 12 suggested the measurement of impedance of artificial ear Type 3.3 and 3.4 [4]. A device, equipped with a 1/2-in. microphone as a constant velocity source and a probe microphone as a pressure sensor, was employed for the measurement of acoustic impedance at a point in the close near-field of the artificial ear.

In this work, to avoid empirical conditioning of design parameters of the sound reproduction system, the electric circuit model based on the electro–mechano-acoustical analogy is derived by employing all the detailed system components [5,6]. Impedance of an artificial ear, Type 3.3 or 3.4, is directly measured by using the multiple microphone technique within a straight duct, which is excited by an external sound source [8]. It is shown that the suggested model with the measured impedance of an artificial ear is in good agreement with the measured result for a test condition in the frequency range of 300–3400 Hz, which corresponds to the narrow communication band defined in the telephone industry.

2. Analogous circuit model

2.1. Receiver model

Thiele and Small's model [5,6] is employed in the electro-acoustic modeling. In this model, both electric system and mechanical

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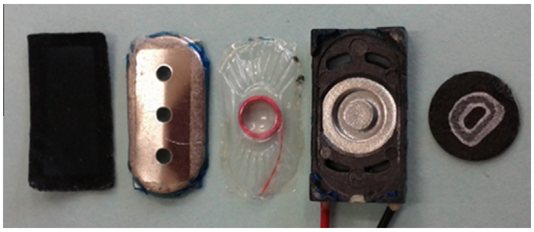

Fig. 1. A typical disassembled receiver unit. From left to right, wire mesh, front cavity cover, voice-coil attached on the diaphragm, magnet with back cavity, and absorbing patch are in order.

system of a mobile phone receiver are lumped and combined with the acoustic path model by using the analogy among electrical, mechanical, and acoustical elements [7]. It is known that electric circuit model yields a reasonable result as long as the diaphragm of loudspeaker can be considered as a linearly oscillating rigid piston, i.e., the entire cone moves fore-aft as a unit without cone breakup.

In many industry, the speaker unit used for the hand-held communication in mobile phone is often called the *receiver unit*. Fig. 1 shows a dissembled view of the receiver unit, in which the dimension of receiver is $12 \times 7 \times 2\ \text{mm}^3$. The voice-coil is attached to the diaphragm which is fixed to the back cavity, and the cavity includes leakage path. The front cavity with three holes is assembled upon the diaphragm, and the wire mesh is glued on top of the cavity which protects the receiver unit contaminated from the dust.

The diaphragm of such a micro-speaker usually functions as both radiating surface and suspension. Here, the moving mass of voice-coil and diaphragm can be directly measured by using an accurate digital scale because only the rim part of the diaphragm is fixed and its mass is negligible.

2.1.1. Equivalent circuit

Electric system of the receiver unit is composed of voice-coil and permanent magnet. Related parameters are the resistance R_e and inductance L_e of voice-coil with the magnetic flux density B of the voice-coil within the length l.

Mechanical system consists of diaphragm and suspension, but the diaphragm also works as a suspension in a micro-speaker as stated before. Involved parameters are the total moving mass M_{mm}, resistance R_{mm}, and compliance C_{mm} of the diaphragm, and the radiating surface area S_d. Here, the total moving mass includes the mass of diaphragm, voice-coil, and oscillating air. Also, the surface area radiating the sound is regarded as the same with the diaphragm area. Assuming a linear time-invariant system, the electric and mechanical system of the receiver unit can be modeled by using an equivalent electric circuit model as depicted in Fig. 2, and its parameters are converted into the acoustic domain. Source

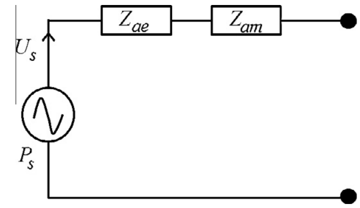

Fig. 2. Electric circuit model for the electro-mechanical system of a receiver unit.

strength P_s, equivalent acoustic impedance of electrical impedance Z_{ae} of voice-coil, and equivalent acoustic impedance of mechanical impedance Z_{am} of receiver at acoustic domain can be derived as

$$P_s = \frac{Ble_g}{(R_e + j\omega L_e)S_d}, \quad Z_{ae} = \frac{(Bl)^2}{(R_e + j\omega L_e)S_d^2},$$
$$Z_{am} = j\omega M_{am} + R_{am} + \frac{1}{j\omega C_{am}}. \qquad (1a, b, c)$$

Once the acoustic path is determined, it can be modeled and connected to the electric and mechanical circuit model of receiver unit in Fig. 2 to predict the acoustic performance of the receiver unit coupled with acoustic path.

2.1.2. Parameter estimation

Lumped parameters of electric and mechanical system of receiver unit are estimated from the measured electric impedance of voice-coil. Before measuring the electric impedance of receiver unit, the electric impedance of voice-coil itself and the total moving mass are obtained in a priori by separate measurements. A precision impedance analyzer (Agilent 4294A) is used to measure the electric impedance Z_{vc} of voice-coil in receiver unit. Electric impedance is measured with 10 receiver samples, and the obtained curves are averaged. Sine-sweeping excitation with sweeping rate of 270 Hz/s is used for a frequency range of 40 Hz–8 kHz. For each receiver unit, sweeping test is conducted 10 times, and the output curves are averaged for each sample. Measured electric impedance curves are shown in Fig. 3 from 40 Hz to 3.4 kHz, for which the magnitude and phase are calculated as

$$\text{Magnitude} = 10\log_{10}|Z_{vc}|, \quad \text{phase} = \frac{\text{Imag}(Z_{vc})}{\text{Real}(Z_{vc})}. \qquad (2a, b)$$

Based on the averaged impedance curve, electric and mechanical parameters are estimated.

2.2. Acoustic path model

When a receiver unit is installed in a mobile phone, it faces a small cavity and holes in the front side, and an electric circuit

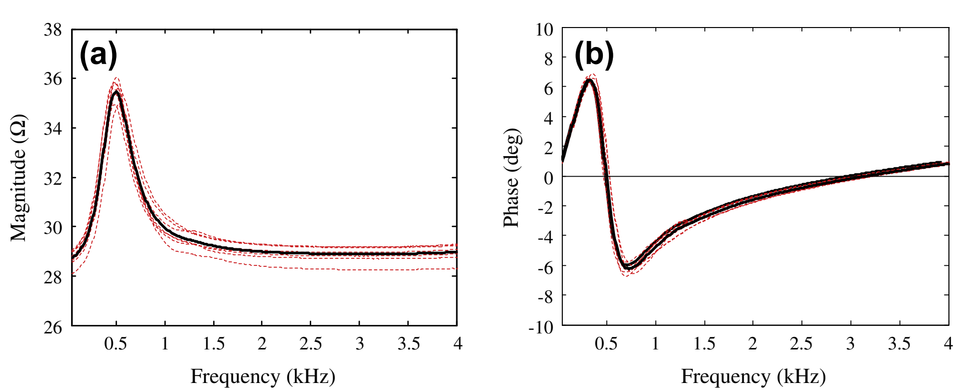

Fig. 3. Measured electric impedance of the receiver unit: (a) magnitude, (b) phase. ······, electric impedance of receiver samples; ——, averaged electric impedance.

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