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Physical characteristics of analog audio cables and their effect on sound quality

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ABSTRACT

This paper deals with the change in sound quality due to an analog audio cable under a high impedance load. It has been quantitatively shown that the signal amplitude dependency of the time constant affects the audible sound quality. Under the handling conditions, a change in the capacitance of the cable due to the signal causes a change in the sound quality. Then, the transient response and the sensitivity of the capacitance change due to the signal were measured for some cables. In addition to showing the characteristics of each cable, we propose conditions that hardly affect sound quality.

1 Introduction

The development of electronic circuit technology has been remarkable, and the quality of reproduced sound has also been improved. As a result, in many cases, the frequency bandwidth and distortion ratio of the reproduced sound fall within a range in which it is difficult to discriminate perceptually^{[1],[2]}. Nevertheless, we often experience that the impression of the sound played depends on the amplifier and cable used. No clear conclusions have been made as to why this phenomenon occurs, but trial and error have been performed based on the experience of engineers.

Several attempts have been made to find the cause of this problem. Some attempts have been made. For example, in [3], distortions caused by loudspeaker cables were measured, but failed with interconnect cables. The author has proposed an approach to look for this cause [4]; it measures physical non-ideal characteristics, reproduces them by digital signal processing, and confirms them. The report showed that using a headphone cable as an example, that the

inductance of the cable changes with the amplitude of the signal affects the sound quality perceptually.

This paper deals with the change in sound quality due to analogue audio cables when the load impedance is high assuming interconnect cables, microphone cables, and instrument cables. The results of measuring the signal amplitude dependence of the capacitance as a transient response for some cables are shown, and the conditions under which sound quality changes are not detected audibly are considered.

The rest of this paper is organized as follows. After describing the change factors of the sound quality in Chapter 2, the audible identifiable range will be described in Chapter 3. Chapter 4 describes the measuring equipment and method used, and Chapter 5 gives the measurement results. It is considered in Chapter 6 before concluding this paper in Chapter 7.

2 Cable types and sound quality change factors

It is an occasional thing we experience that changing the cable that carries the audio signal changes the

perceived sound quality. There are several types of the cables, microphone cables, interconnect cables, guitar shield cables, headphone cables, loudspeaker cables, and the like are used to transfer analogue signals. There are factors in the sound quality change, and when analysing the sound quality change, it is necessary to consider each major factor separately.

Earlier, the author examined the change in sound quality due to the headphone cable^[4], but from the experimental results, it was concluded that the factor was related to the change in cable inductance due to the current flowing through the cable. It is considered that the cable was slightly physically deformed by the electromagnetic action.

This paper deals with interconnect cables, which are generally called line cables. One of the characteristics is that the input impedance on the signal receiving side is relatively high (1 k or higher), so that the current flowing through the cable itself is small. Therefore, it is considered that the change in characteristics due to the electromagnetic force is small as in a headphone cable. Instead, it is conceivable that the electrostatic force acts by the signal voltage and causes physical deformation, thereby changing its characteristics. Since the change in the inductance of the cable has a small effect on the transfer signal due to the high impedance input, attention is paid to the change in the capacitance. In this case, the output impedance of the signal transmitting side is relevant.

Let us model the cable as a lumped parameter system. Assuming that the capacitance of the cable is C , the output impedance is r , and the input impedance is sufficiently high, the transfer function of signal transmission by the cable is as follows.

$$G(s) = \frac{1}{rCs + 1}, \quad (1)$$

where it is assumed the DC resistance and inductance of the cable are sufficiently small. Here, consider a case where the cable capacitance C changes according to the signal voltage.

$$C = C_0 + \delta C, \quad (2)$$

where δC is a capacitance change portion due to the signal voltage.

Here, considering the case where the cut-off frequency in the cable transfer is sufficiently higher than the audible bandwidth, the transfer function to the difference due to the signal transfer is calculated as follows.

$$1 - G(s) = \frac{rCs}{rCs + 1} \approx rCs \equiv (T + \delta T)s, \quad (3)$$

where $T = rC_0$ and $\delta T = r\delta C$.

The concern here is how large the δT contributed by the signal voltage will not affect the audible sound quality of the transferred signal. Note that what matters is the value of the change in the time constant, which is hardly related to the time constant itself. That is, the change in the capacitance of the cable is important, and the value of the capacitance itself is not a significant problem. However, in general terms, a cable having a large capacitance tends to have a large change.

3 Perceptual sensitivity of time constant deviation^[4]

Regarding the value of δT , that does not affect the auditory sound quality, the experimental results used in the report on the effect of the headphone cable are useful. This is an experiment in which, when the time constant changes according to the signal, up to the change of the time constant in which range, the sound quality does not change. The change of the time constant is simulated by digital signal processing, and the result is examined by listening with headphones. The model at the time of the simulation is shown in Fig. 1, where the first-order lag element having a time constant of 1 ms simulates the dynamics of a change in the physical shape of the cable. Subjects were normal hearing males and females between the ages of 21 and 24, with no audio experience and no training in listening.

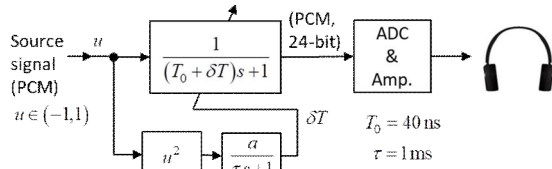


Figure 1. Configurations of perceptual sensitivity test.

		time constant deviation coefficient a [s]					
		$-4e-11$	$-4e-12$	$-4e-13$	$4e-13$	$4e-12$	$4e-11$
Subjects	A	D	D	D	-	-	D
	B	D	D	D	-	-	D
	C	D	-	-	-	-	-
	E	D	-	-	-	-	D
	F	D	D	-	D	D	D
	G	D	D	-	-	-	D
	H	D	D	-	-	-	-
	I	D	D	-	-	D	D
	J	-	-	-	-	-	D

D: different, -: same

Table 1. Perceptual sensitivity test result for inductance deviation.

From this result, although roughly, it can be seen that if the variation of the time constant is from -1 to 10 ps in consideration of the boundary value, three-quarters of persons cannot recognize the change in the sound quality due to the variation of the time constant. Note that the range is asymmetric with respect to the sign. The range that almost all people cannot recognize may be considered to be one tenth of that. This is the result of listening with headphones. When using loudspeakers, the result can be a little different, and depending on other playback environments, it is one index that gives a limit to the discrimination of changes in sound quality.

From the results of the experiment, it can be seen that a small fluctuation of the time constant has high auditory sensitivity, but this uses a parameter with a unit of time to express the magnitude of the non-ideal component included in the signal. Note that this does not mean that temporal fluctuations of such magnitude can be detected.

4 Measuring device and measuring method

To measure the dependence of the capacitance of the cable on the applied voltage, a measuring device was manufactured. This is because measurement is difficult with a commercially available device. The electric circuit of the measuring device is shown in Fig. 2. The measurement can be performed for both the balanced cable and the unbalanced cable. When measuring the unbalanced cable, SW1 is tilted to the $\delta UB\delta$ side, and the cable is connected through the TS plug. When measuring a balanced cable, SW1 is tilted to the $\delta BAL\delta$ side and the cable is connected through a TRS plug. The voltage applied to the cable is monitored through CH1, and the current flowing through the cable is converted to a voltage by resistors, amplified by an instrumentation amplifier, and measured through CH2. The output signals of CH1 and CH2 are converted to a 48 kbps PCM signal by Fireface UCX and recorded.

The capacitance of the cable is detected by a tone signal of 10.05 kHz 0.336 V_{rms}. To change the voltage applied to the cable, a tone burst signal of 1 kHz 2.38 V_{rms} was superimposed. The on period is 10 s and the off period is 10 s. To reduce the measurement error noise, data was measured 25 times during 20 s and averaged. The acquired data was taken out every 4800 points, multiplied by the Hann window, and DFT-transformed to calculate a spectrum. The capacitance was calculated by dividing the 10.05 kHz component spectrum of the current detection signal by that of the voltage monitor signal and taking the imaginary part. The cable to be measured was 1 m in length.

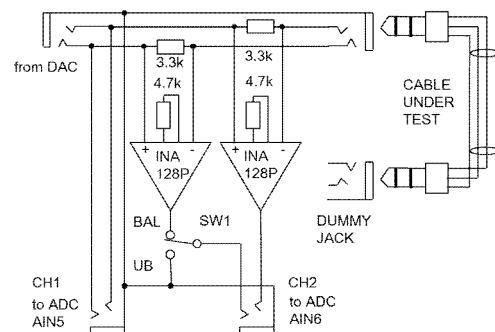


Figure 2. Schematics of measurement circuits.

In order to eliminate the residue of the common-mode signal rejection of the operational amplifiers, the measurement result without cable is subtracted from the measurement result with each cable.

5 Measurement result

The voltage dependence of the capacitance was measured for some unbalanced cables. Fig. 3 shows the time responses of the capacitance change of general cables used for a high-frequency signal, and Fig. 4 shows the measurement results of the cables for an audio signal. The effective value of the applied voltage changes in a pulse shape, decreases stepwise at time 2 s, and increases stepwise at time 12 s. Some cables have a temporal trend due to aging.

AT364, KM-A4-10K2 and BELDEN9396 are dedicated interconnect cables. BELDEN9395, BELDEN9394, MOGAMI 2319 and MOGAMI 3368 were developed as guitar shielded cables. The δ L-4E6S 2-2 ϕ is a twisted pair with a shield connected to the L-4E6S, which is a 4-core shielded cable, to make it unbalanced drive.

In all cables, the change in capacitance was positively related to the applied voltage amplitude. The magnitude of the capacitance change depends on the type of cable. Some have a trend over time, which is due to the unaged cable used for the measurement. The shape of the transient response of the capacitance change to the applied voltage change is slightly different depending on the cable. For example, in the RG-174/U, which is a general high-frequency coaxial cable, the capacitance change has a shape similar to the applied voltage, whereas in the AT364A, which is dedicated to an interconnect cable, the capacitance is rising over a period of 2 s when the applied voltage increases. In BELDEN 9394 of the guitar shield, after the applied voltage decreases, the capacitance temporarily decreases and then temporarily increases 0.6 seconds later. The characteristics of the transient response shape of the capacitance change in each cable can be represented by the above-mentioned slow rise when the applied voltage rises and kickback when the applied voltage falls, and the degree differs for each cable.

Table 2 shows the degree of voltage dependence of capacitance for each cable. These are obtained by performing multiple regression analysis on the capacitance based on the applied voltage and time. Dependencies differed between cables, but no dramatic differences were found among them.

Next, the result of the transient response in the balanced cable is shown in Fig. 5. The δ 1.5C-2V balance ϕ is a balanced drive using two 1.5C-2V cables. Note that the scale of the vertical axis of the graph has been changed because the dependence of the capacitance on the applied voltage was smaller in the balanced cable than in the unbalanced cable. The reason why the voltage dependency is smaller is that the voltage of the signal interconnect with respect to the ground is half that of the case where the voltage is unbalanced. However, the stress applied to the conductor by applying a voltage is proportional to the square of the voltage. Table 3 lists the dependence of the capacitance on the applied voltage. Among them, the voltage dependency of L-4E6S is large, which is presumed to be due to the signal line having a four-core structure. The results given here are for the case driven by a balanced signal. Even if the cable is balanced, the results will be different if driven by an unbalanced signal.

6 Considerations

It is considered that the main factor of the change in the capacitance of the cable is that the cable is physically deformed by the electrostatic force generated by the applied voltage. Since the electrostatic force is proportional to the square of the potential difference, the capacitance also changes in proportion to the square of the applied voltage. Therefore, the ratio of change in capacitance was normalized by the square of the applied voltage. Note that for the above reasons, there is no cancellation of capacitance changes in balanced cables.

When quantitatively evaluating the change in sound quality due to the change in capacitance of the cable, the change in the time constant is calculated by multiplying the change ratio put here by the cable length, the square of the maximum applied voltage,

and the output impedance. If the value is 10^{-11} s or less, a change in the sound quality due to a change in the capacitance of the cable is difficult to recognize.

In practice, it is sufficient to lower the output impedance so as to satisfy the condition.

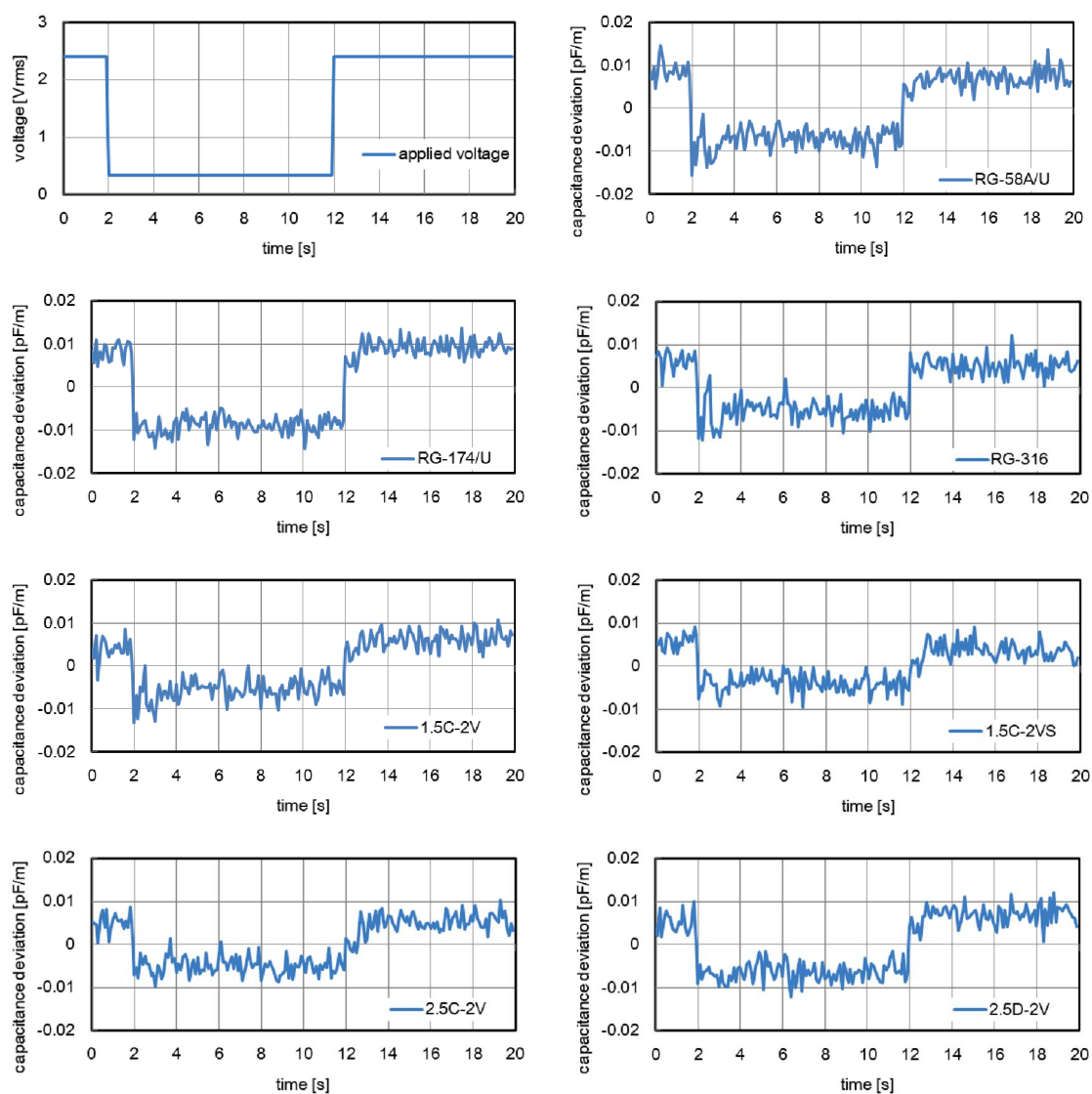


Figure 3. Capacitance deviation responses of general cables due to applied voltage.

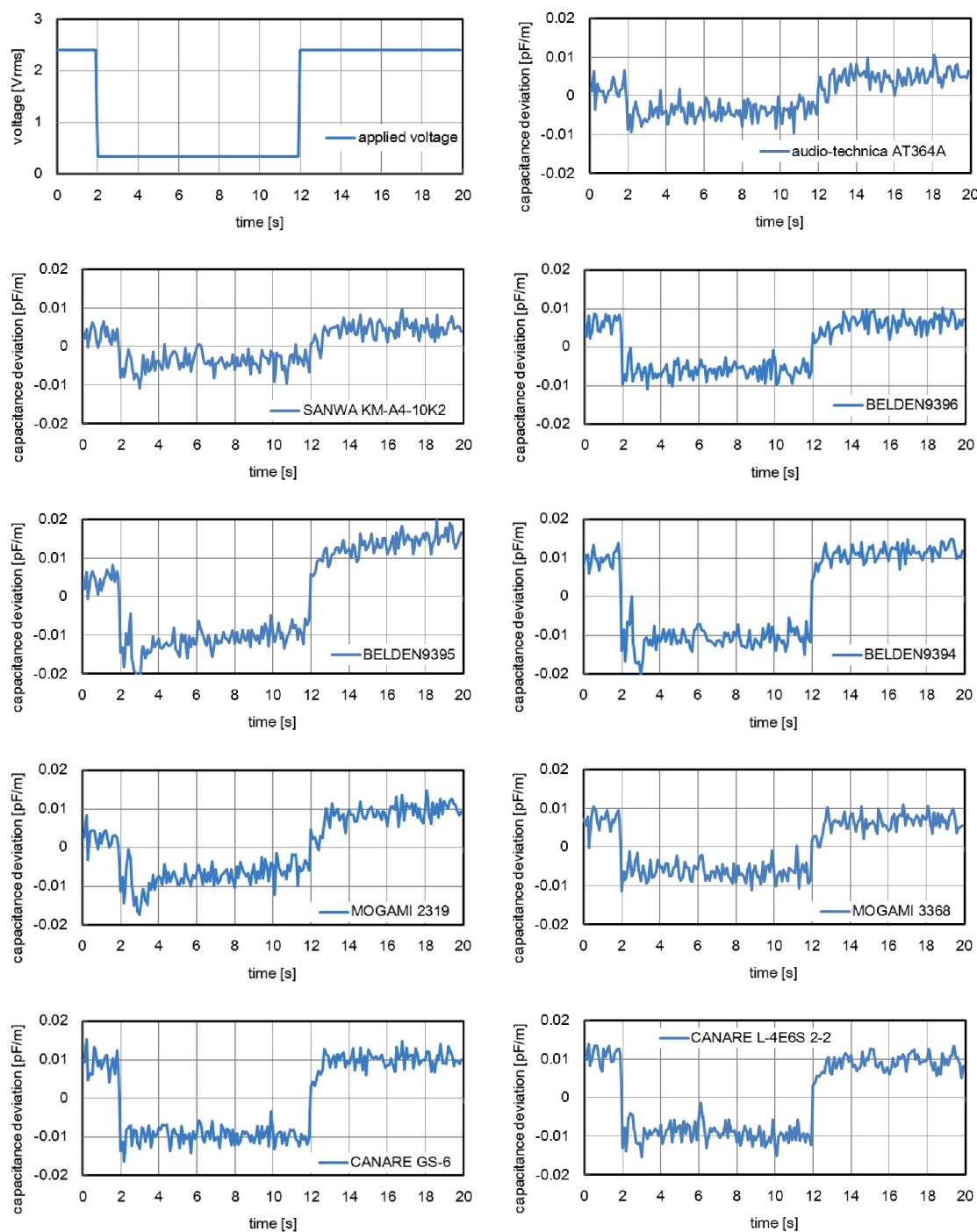


Figure 4. Capacitance deviation responses of audio cables due to applied voltage.

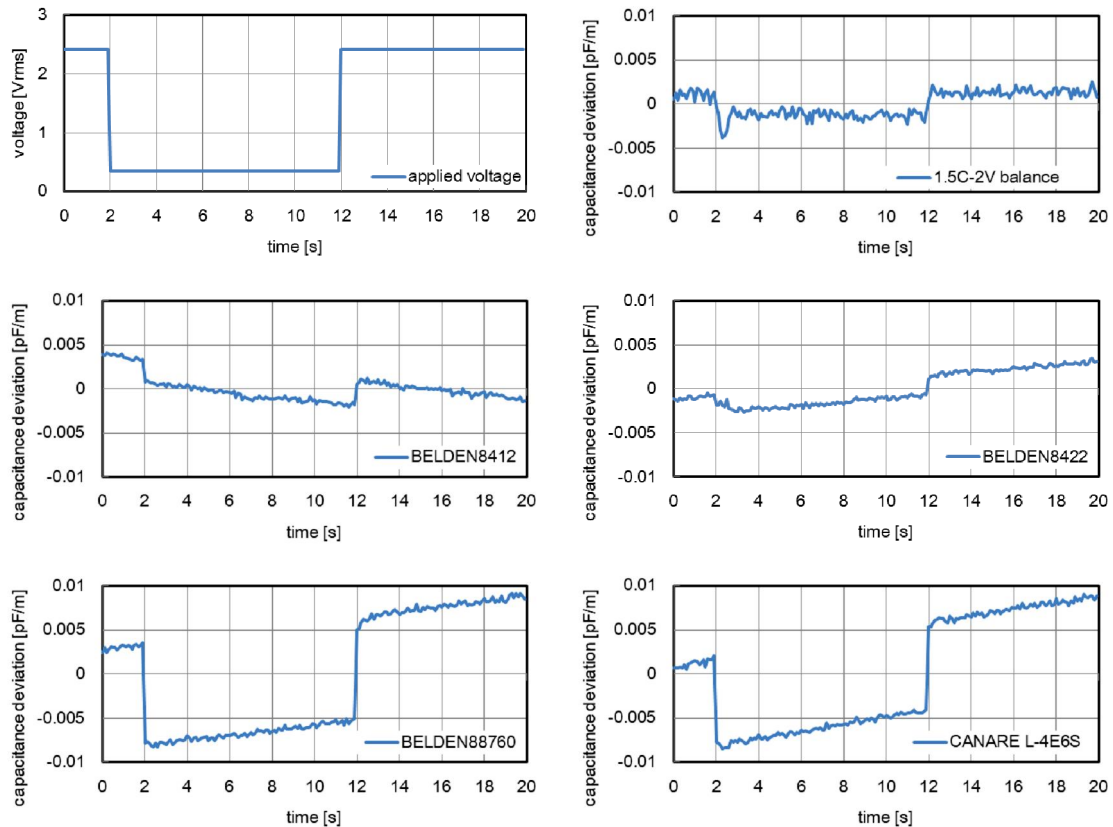


Figure 5. Capacitance deviation responses of balanced cables due to applied voltage.

The magnitude of the voltage applied to the cable varies greatly depending on the application. In the case of an interconnect cable, care must be taken because a high voltage signal is used to secure the S/N ratio. In the case of a microphone cable, since the signal level is low, it is considered that there is often no problem. In this case, the superposition of the DC voltage does not matter. In the case of a guitar shielded cable, the output impedance of the musical instrument is high and the cable cannot be shortened, so the conditions are not good.

The change in capacitance of a cable depends on its structure and materials used, but it is limited by the use of the cable. For example, for a guitar shielded cable, many requirements must be met. Those contain high flexibility, mechanical toughness, very low leakage capacitance, suppression of static

electricity noise due to mechanical deformation, *etc.* Therefore, it should be noted that although the ratio of change in capacitance of the guitar shielded cable is large, the cable is also considered to be a part of the musical instrument, and there is no guarantee that the presence or absence of a change in sound quality directly leads to the quality of the cable. However, the results of this measurement should be used in some way to evaluate the cable. Because it is a musical instrument, engineering evaluation may not be easy, but it is desirable to be able to relate to the experience of many people.

In some cases, the change in the capacitance of the cable causes a small time lag with the applied voltage, but in other cases, it changes gradually for about 2 seconds depending on the cable, and appears as kickback after 0.6 seconds.

cable	capacitance [pF/m]	dependency [pF/V ² /m]	ref.
RG-58A/U	103	2.87E-03	
RG-174/U	99	3.38E-03	
RG-316	99	1.96E-03	
0.8D-QEV	100	2.22E-03	
1.5C-2V	69	1.98E-03	
1.5C-2VS	72	1.69E-03	
1.5D-2W	103	2.61E-03	
2.5C-2V	68	1.90E-03	
2.5D-2V	104	2.37E-03	
audio-technica AT364A	107	1.38E-03	
SANWA KM-A4-10K2	83	1.45E-03	
BELDEN9396	121	2.34E-03	
BELDEN9395	175	3.71E-03 GS	
BELDEN9394	196	4.09E-03 GS	
MOGAMI 2319	151	2.34E-03 GS	
MOGAMI 3368	72	2.52E-03 GS	
CANARE GS-6	150	3.68E-03 GS	
CANARE L-4E6S 2-2	214	3.75E-03 4C	

GS: guitar shield cable, 4C: 4-core cable

Table 2. Capacitance dependencies of unbalanced cables on signal voltage.

cable	capacitance [pF/m]	dependency [pF/V ² /m]	ref.
1.5C-2V balance	31	7.62E-04 coax	
BELDEN8412	111	8.64E-04 2C	
BELDEN8422	76	6.26E-04 2C	
BELDEN88760	175	3.56E-03 2C	
CANARE L-4E6S	433	3.01E-03 4C	

coax: coaxial, 2C: 2-core, 4C: 4-core

Table 3. Capacitance dependencies of balanced cables on signal voltage.

Such a phenomenon is often seen in the case of unbalanced cables, and has a characteristic that it is asymmetric with respect to rising and falling of the applied voltage level. Naturally, it is thought that such characteristics affect the sound quality change in auditory sense, but this time, it is not evaluated. This is because the transient change of the inductance could not be modelled, yet. It is inferred from the observation results that the model becomes nonlinear. Future progress is expected.

This time, a quantitative index of sound quality change due to cables is dealt with, but there are other possible sound quality change factors, *e.g.* connectors and amplifiers. In a sound system, even if the sound quality change of only some of the elements is evaluated, there is a possibility that a balanced system cannot be constructed. It is desired

to establish a sound quality change index similar to that of the cable for other elements.

7 Conclusions

In the case of audio signal transmission over an audio cable, it is shown that the change in the capacitance of the cable due to the voltage of the transmitted signal causes an audible change in sound quality, and the voltage dependence of the capacitance is measured for some unbalanced and balanced cables. In addition, it has been quantitatively shown that the output impedance on the drive side may be reduced to a level at which a change in sound quality due to a change in cable capacity cannot be detected. However, it was also detected that the cable capacity could change slowly with signal voltage, and analysis of the effect of this phenomenon on audible sound quality remained.

There are many factors that affect sound quality in the process of recording and reproducing sound. Focusing on only one factor does not result in a balanced system as a whole. It is desired that a quantitative evaluation index be given to other audible sound quality change factors.

References

- [1] C. J. Moore, An Introduction to the Psychology of Hearing 6th edition, Academic Press (2013).
- [2] S. Temme, P. Brunet, P. Qarabaqi, "Measurement of Harmonic Distortion Audibility Using a Simplified Psychoacoustic Model ó Updated" AES 51st International Conference: Loudspeakers and Headphones (2013).
- [3] R. Black, "Audio Cable Distortion is Not a Myth!" 120th AES Convention, Paper No. 6858 (2006)
- [4] A. Yoneya, "Perceptually Affecting Electrical Properties of Headphone Cable ó Factor Hunting Approach" 147th AES Convention, eBrief:532 (2019)