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The study of high efficiency driving of HIFU transducers

HIFU 用トランスデューサーの高効率駆動の研究

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1. Background

High Intensity Focused Ultrasound (HIFU) can directly damage the tumor such as cancer without surgically opening the living body by the heating / cautery action of the strongly focused ultrasound. It is also a clinically expected tool due to the possibility of topical treatment with Drag Delivery System (DDS) in combination with extremely few side effects.

When viewed from the equipment side, HIFU is energy application of ultrasound, and as much as 200 to 500 W of electric power must be supplied to a transducer.

When supplying electric power, loss occurs in the drive circuit or the transmission path, heat is generated, an aggressive heat dissipation structure is required to dissipate this heat, the system itself becomes large, ultrasound Good handling of the device is impaired.

By eliminating the transmission cable and further matching the impedance of the drive circuit and the transducer, the power transmission efficiency was improved by about 40 points compared with the case of using the cable. And I presented a transducer integrated drive circuit using a small semiconductor at this symposium in 2016.

The frequency dependence of the power loss of the transmission cable is discussed this time.

2. Objectives

Consideration on Frequency Dependence of Power Loss by transmission cable.

In general, the driving circuit uses a switching method to suppress the power loss of the circuit itself. Therefore, the driving waveform becomes a rectangular or a trapezoidal wave, and it contains many harmonics (mainly odd order). It reveals that harmonic components are consumed by only cable, not transducer.

3. Method

When the excitation voltage is applied to the load, the generated power $\dot{P}$ is expressed by the equation (1)

$$\dot{P} = P_a + jP_r = {v_{RMS}}^2\dot{Y} = {v_{RMS}}^2(G + jB) \quad \cdots (1)$$

Here, P_a: active power [W], P_r: reactive power [var], $\dot{Y}$: Admittance [S] of load, G: Conductance [S] of load, B: Susceptance [S] of load, v_{RMS}: excitation the effective value [Vrms] of the voltage.

Since the active power is the "working power" that becomes the sound output and the heat (Joule heat and heat caused by the vibration of the transducer), if the Conductance of the load is known, the power consumption is known too.

Supposing that $g_{TD}(f)$ is the frequency characteristics of the Conductance of only the transducer, and $g_{TD\_CABLE}(f)$ is the frequency characteristics of the Conductance when passing through the coaxial cable for power transmission to the transducer, the power consumed by the cable is expressed by the equation (2).

$$p_{a\_CABLE}(f) = v(f)^2\{g_{TD\_CABLE}(f) - g_{TD}(f)\} \cdots (2)$$

The outline specifications of the transducer and cable used for the experiment are,
Transducer: Nominal frequency=0.5 MHz, PZT single element 25 mm diameters, dumped capacity=650 pF, Cable: AWG40 thin coaxial cable, 110 pF/m, 2 m length.

4. Result

Fig. 1 shows the Admittance characteristics of the test transducer. Conductance value is almost zero except the resonance point.

Fig.2 shows the Admittance characteristic when passing through the coaxial cable to this transducer. Conductance characteristic rises depend on frequency.

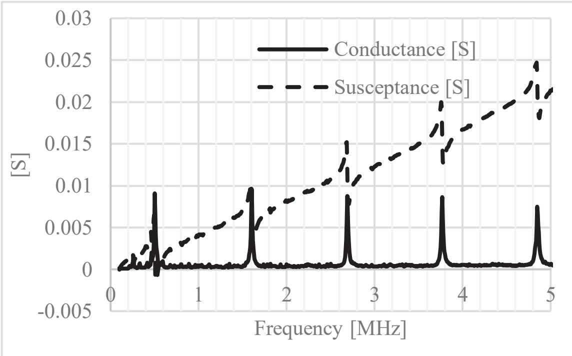

Fig.1 Admittance characteristics of transducer

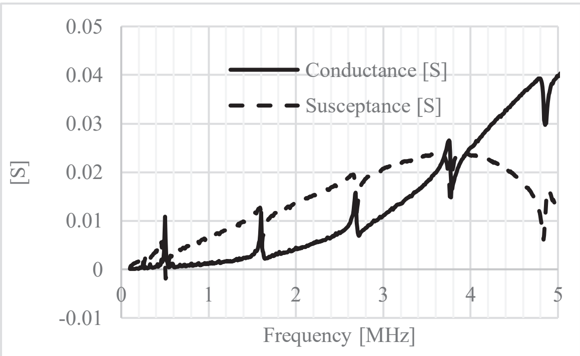

Fig.2 Admittance characteristics via coaxial cable

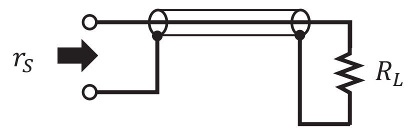

Fig.3 Equivalent circuit for measuring of parallel resistance

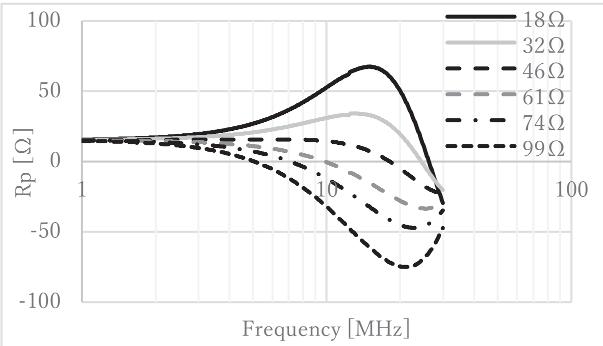

Fig.4 Parallel resistance of only cable

5. Consideration

Consider the power consumption when applying a distortion wave such as rectangular or trapezoid or sawtooth and so on, to the load of the characteristics in Figs. 1 and 2.

As is well known, the frequency components of the distortion wave include a fundamental component and several kinds of harmonics. When this waveform is applied only to the transducer of Fig. 1, the higher order vibration frequency of the transducer is slightly different from the harmonic frequency of the distorted wave, so Conductance at the harmonic frequency becomes almost zero, accordingly electric power is hardly consumed by harmonics. However, in the case of Fig. 2, the cable has increased Conductance with frequency, indicating that power is consumed by the harmonic components of the driving waveform.

Next, think about the reason why Conductance's frequency characteristics are not zero when passing through a cable.

The parallel resistance r_S when this cable is terminated with the fixed resistance R_L is measured. The equivalent circuit of measurement is shown in Fig.3.

However, R_L has frequency characteristics also, not pure resistance. So that, changes due to the frequency of R_L are canceled by $r_S(f) - R_L(f)$, and the frequency characteristics of parallel resistance of only cable can be obtained. (Fig.4)

In the Fig. 4, it can be seen that the frequency characteristic in the case of terminating at about 46 Ω is almost flat, this is indicating the characteristic impedance of this cable.

When R_L is shifted from the value of the characteristic impedance, the frequency characteristic changes and the resonance point appears. This is the resonance point of the standing wave generated by the reflection caused by impedance un-matching. The increase in Conductance mentioned above is caused by un-matching the impedance between the cable and the transducer.

On the other hand, when attention is paid to the low frequency at 1MHz in the graph of Fig.4, it approaches approximately 15Ω. This resistance value is the DC resistance inherent in the cable, which causes loss and generates Joule heat.

6. Conclusion

When the switching type drive circuit is directly connected to the transducer, there is almost no power consumption due to harmonic components of the drive waveform. Harmonic components in the case of passing through the cable are consumed by the cable. Therefore, it is unnecessary to make the driving waveform of sine wave in the case of direct connection.

7. References

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