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2013-11-29

CHARACTERIZATION AND OPTIMIZATION OF A LOUDSPEAKER

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ABSTRACT

The aim of this report is to examine the properties such as the sound output, impedance and distortions dependence on frequency and the basic loudspeaker parameters of a simple closed-box loudspeaker.

A PC with the software CLIOwin is used to collect and analyze the data. After analyzing the data the loudspeaker is redesigned into a vented-box loudspeaker. CLIOwin is then used to verify that the new loudspeaker is correctly designed with a smooth frequency curve, with a lower distortion at low frequencies. The cut off frequencies is supposed to be lowered. Also the sound radiation intensities from the loudspeaker element and the vent opening are checked.

The results show that the smoothness of the frequency curve of the new loudspeaker is not improved. Considering distortion the new loudspeaker was not improved. The sound radiation intensities from the element and the vent shows that the new loudspeaker has a lower cut off frequency.

Noninvasive Measurement Techniques
Supervisor(s): Bertil Sundqvist

1. INTRODUCTION

The simplest loudspeaker available is the closed box loudspeaker but just by making a well design hole in this simple box a bass-reflex loudspeaker is created. The advantages with the bass-reflex loudspeaker is that it can play lower frequencies and the sound it generates is less distorted than the sound is less distorted than the sound from a simple closed box loudspeaker.

The aim of this report is to examine the properties such as the sound output, impedance and distortions dependence on frequency and the basic loudspeaker parameters of a simple closed box loudspeaker. The goal then is to redesign the closed box loudspeaker into a vented box or bass-reflex loudspeaker and verify by new measurements that the bass-reflex has a lower cut off frequency and also lower distortion at low frequencies. It should also be verified that sound at low frequencies radiates from the hole and at higher frequencies from the loudspeaker element and also that the new loudspeaker has a smooth frequency curve.

2. THEORY

In this section the theory equations and parameters used in the report are described. Also a short description of the microphone used is included.

2.1 Thiele and Small parameter description

The Thiele and Small parameters (T&S) is a range of parameters which were brought about to standardize the description of cone loudspeakers. In this section these are described.

F_s [Hz] is the resonance frequency of the driver including air load. This is the when all the moving parts of the loudspeaker resonates. The cone responds stronger to frequencies near its resonant frequency. The resonance frequency can be approximated as

$F_S = EPB \cdot Q_{ES}$ (see [1]) where Q_{ES} is described below and EPR is the efficiency bandwidth product.

V_{as} [L] is the volume of the air that has the same acoustic compliance as the driver suspension. This volume can be approximated as (see [1]) $V_{AS} = \frac{V_b}{20 \cdot Q_{TS}^{3.3}}$ where V_b is the volume of the enclosure, and Q_{TS} is described below.

R_E [Ω] is the electrical resistance of the voice coil

Q_{MS} is the ratio of energy storing to the energy dissipative mechanisms at the resonance frequency (F_s) considering mechanical losses only.

Q_{ES} is the ratio between energy storing and energy dissipative mechanisms at the resonance frequency (F_s) considering electrical losses only i.e. the ratio between reactance to the resistance.

Q_{TS} is the total ratio between the energy storing and the energy dissipative mechanisms at the resonance frequency (F_s).

B·l [T·m] is the motor strength

dB_{SPL} is the pressure produced by the driver 1m from it when driven by 2.83V.

S_D [m^2] is the effective area of the driver cone.

C_{MS} [m·N] is the mechanical compliance of the driver suspension i.e. its ratio of strain to stress.

M_{MS} [kg] is the mechanical mass of the driver cone assembly including air load.

R_{MS} [Ω_M] is the mechanical resistance of driver suspension losses.

C_{AS} [$m^5 \cdot N^{-1}$] is the acoustic compliance of the driver suspension which can be written as $C_{AS} = \frac{V_b}{\gamma P_A}$, where γ is the adiabatic coefficient of the system, V_b is the volume of the box and P_A is the atmospheric pressure.

M_{AS} [$kg \cdot m^{-4}$] is theacoustic mass of the driver cone assembly including reactive air load.

R_{AS} [Ω_A] is the acoustic resistance of driver suspension losses.

C_{MES} [F] is the electrical capacitance representing the driver's total moving mass.

L_{CES} [H] is the electrical inductance representing the driver's mechanical compliance.

R_{ES} [Ω] is the electrical resistance representing the driver's mechanical losses.

R_{AT} [Ω_A] is the total acoustic resistance of the driver.

R_{MT} [Ω_M] is the total mechanical resistance of the driver.

M_{MD} [kg] is the mechanical mass of the driver cone assembly excluding air load.

Z_{MIN} [Ω] is the minimum impedance in the frequency range above the resonance frequency.

Z_{MAX} [Ω] is the impedance at the resonance frequency

Z_{AVG} [Ω] is the average of the impedance modulus over the measured frequency range.

η_0 [%] is the free air reference efficiency.

L_{1kHz} [H] is the inductance at 1kHz.

L_{10kHz} [H] is the inductance at 10kHz.

2.2 Closed box loudspeaker vs. Bass-reflex loudspeaker

A closed box loudspeaker is a loudspeaker enclosed in sealed box. A closed box with a hole in it is a vented box loudspeaker i.e. a bass-reflex loud speaker. A box with a hole in it represents a Helmholtz resonator i.e. at a certain frequency the pressure in the box and the air velocity at the opening is going the rise substantially. If a loudspeaker is placed in the box the cone's velocity is going to be low at the frequency where the pressure in the box is large. There are two advantages to a bas reflex in comparison to a sealed box. The first is that sound waves come from both the cone and the hole (over a certain frequency range) causing the lower limit of the frequency range to drop. The other advantage is the by bringing down the speed of the cone the distortion of the sound becomes lower. However if the box is small (1-2 times the optimal volume of a closed box) the second advantage is the only one that is noticeable.

Using some of the T&S an approximate length of the hole in a bass-reflex loudspeaker can be approximated as (see [1])

$$L = \frac{5.76 \cdot 10^8 r^2}{f_b^2 V_b} - 0.0372r \tag{1}$$

Where r is the radii of the hole and f_b is the tuning frequency of the loudspeaker system which can be approximated as

$$f_b = \left(\frac{V_{AS}}{V_b}\right)^{0.31} F_s \tag{2}$$

2.3 Capacitive microphone

A capacitive microphone consists of two electrodes, one fixed and one bendable like a membrane. Between them there is a certain pressure. When the pressure outside the membrane is higher than the pressure between the electrodes the membrane starts to bend inwards and vice versa. The capacitance of the plates changes when the distance between them changes i.e. the voltage difference between the two plates change So an approximation of the measured pressure is $P = c \cdot V$, where c is a constant called the microphone sensitivity and V the voltage given by the microphone

Since it reacts to pressure differences it reacts to sound waves which cause pressure differences. The sound amplitude can be measured by the computer program CLIOwin from knowing the microphone sensitivity.

3. EXPERIMENTAL SETUP AND PROCEDURE

The experiment is carried out using the experimental gear and procedure described in this section.

3.1 Gear and setup

To carry out the experiments we use a loudspeaker element and a loudspeaker box with an auxiliary port. This port can be opened or closed in order to create a vented-box or closed-box loudspeaker. The setup also requires an amplifier, a preamplifier and a calibrated capacitive microphone. A PC with the software CLIOwin is used to gather the data. The gear can be seen in Figure 1 and Figure 2.

Figure 1. Closed-box loudspeaker together with the microphone used in measurements.

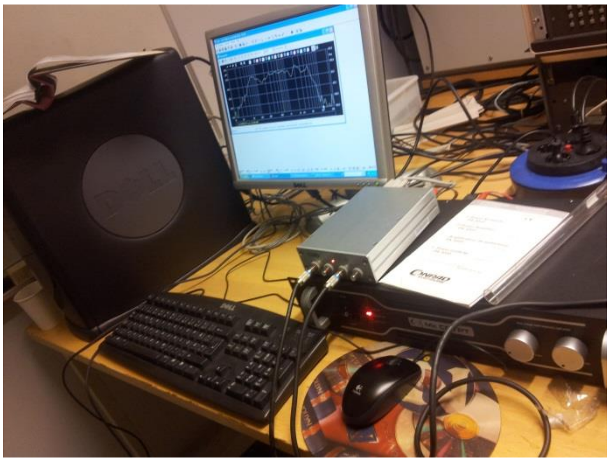

Figure 2. PC, amplifier and preamplifier used in the measurements.

To create a vented-box loudspeaker with different tube lengths we simply open the port and tape tubes of different lengths into the hole. The position (inside or outside) of the tubes is of no major importance as it is the volume of the tubes that decides the effect it has on the sound parameters. Some of the different tubes are seen in Figure 3. The lengths of the tubes vary from 4.5cm to 27cm and are measured using a ruler.

Figure 3. Some of the different tubes used in the experiments.

3.2 Measuring the impedance of the loudspeaker

To measure the impedance of the loudspeaker we simply connect the preamplifier directly to the loudspeaker. The circuit diagram used is seen in Figure 4.

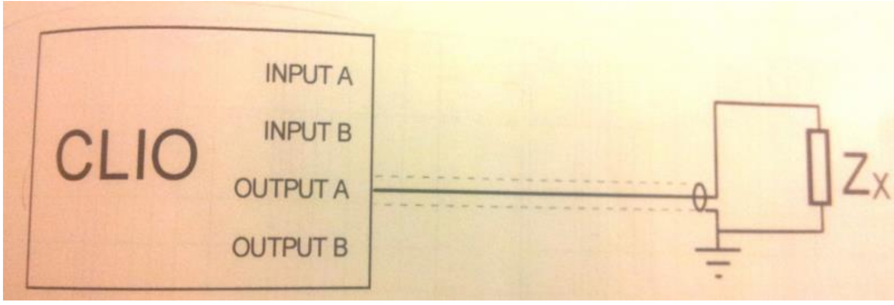

Figure 4. Circuit diagram used to measure the impedance of the loudspeaker.

The sinusoidal mode of CLIOwin is used to gather the impedance data. The resolution is set to $1/24\ Octave$ and the program is set to measure Ω. In our measurements the output amplitude is set to $+5dB$. The plots from CLIOwin are saved and the loudspeaker box is modified with different tube lengths between each measurement.

3.3 Measuring the sound output amplitude, distortion and T&S-parameters

To measure the sound output amplitude and distortion of the loudspeaker as functions of frequency the circuit diagram seen in Figure 5 is used. This diagram is also used to measure the T&S parameters. In CLIOwin the sensitivity of the microphone is set to 37.9, which corresponds to the real sensitivity of the microphone used.

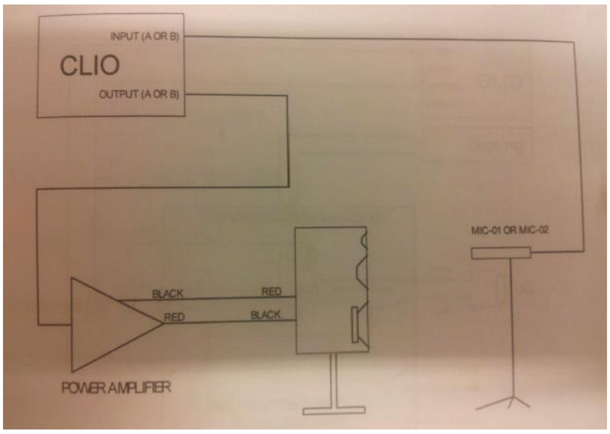

Figure 5. Circuit diagram used to measure sound output amplitude, distortion and T&S parameters.

3.3.1 Measuring sound output amplitude

To measure the sound output amplitude the sinusoidal mode of CLIOwin is used. The program is set to measuredBV, which is a measure of sound input amplitude. As the sound output is externally modified with an amplifier, the output of the signal from CLIOwin is hard to control. In our experiments we set this to $\pm 0dB$, but it is not of importance.

The positioning of the microphone is of interest. To measure the total output of the loudspeaker the setup seen in Figure 1 is used. To measure the sound output of the vent of the vented-box loudspeaker the setup seen in Figure 6 is used.

Figure 6. Measurement setup for measuring the sound output from the vent of a vented-box loudspeaker with an applied tube.

3.3.2 Measuring distortion

To measure the distortion of the loudspeaker the experimental setup seen in Figure 1 is used. Sinusoidal mode of CLIOwin is used, but set to measure the total harmonic distortion (THD) of the sound input, dBV.

3.3.3 Measuring the T&S-parameters

To measure the T&S-parameters two impedance measurements are made. One is made with normal circumstances and the other is made with an applied known mass onto the loudspeaker cone. These two measurements are used by CLIOwin to retrieve the T&S-parameters.

3.4 Comparing sound of loudspeakers using different tube lengths

To compare the sound qualities of the loudspeaker we analyze the sound output amplitude versus frequency plots. As the closed-box loudspeaker has trouble dealing with really low frequencies we want to help the loudspeaker by amplifying these frequencies by applying the tube. We record sound output from the vent using every tube available. The data from these measurements are saved to compare to each other.

As the data at all non-low frequencies will be the same for every plot the plots are modified. The modification is done by subtracting with the data from the closed-box loudspeaker.

4. RESULTS

In this section the results retrieved from the experiments are demonstrated as plots or tables.

4.1 Impedance

The results from our measurements of the impedance of the loudspeaker are shown for three types of loudspeakers. Figure 7 shows the results of measuring the impedance with the closed-box and vented-box loudspeakers as well as the vented-box loudspeaker with a 27cm tube.

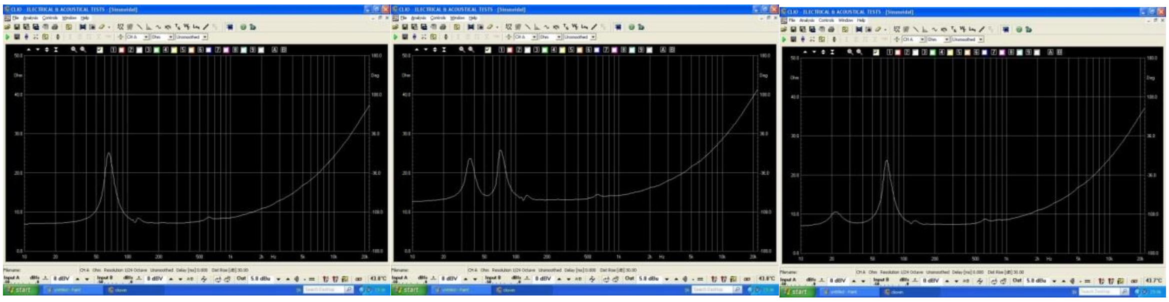

Figure 7. Results from measuring the impedance versus frequency of the closed-box (left), the vented-box without tube (middle) and the vented-box with a 27cm tube (right) loudspeakers.

4.2 Sound output amplitude

The results from our measurements of the sound output amplitude are shown for three types of loudspeakers. Figure 8 demonstrates the sound output amplitude for the closed-box and vented-box loudspeakers.

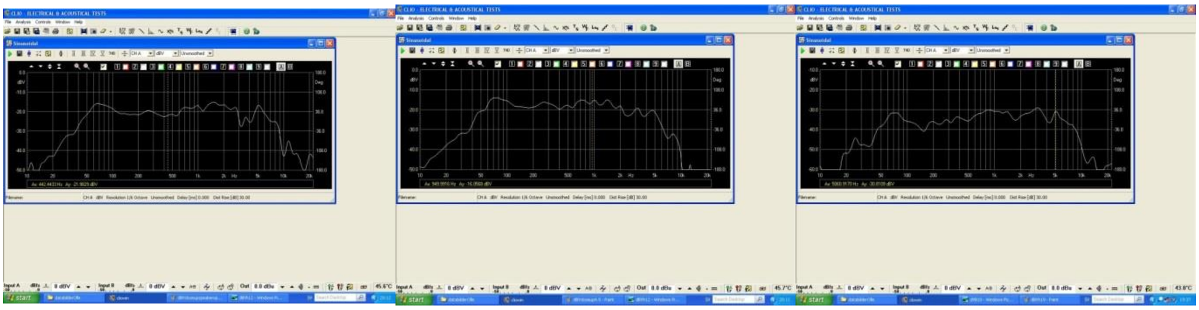

Figure 8. Results from measuring the sound output amplitude versus frequency of the closed-box (left), the vented-box without tube (middle) and the vented-box with a 27cm tube (right) loudspeakers.

Figure 9 demonstrates a close-up measurement, seen in Figure 6 of the sound from the vent, with the 27cm tube applied. The

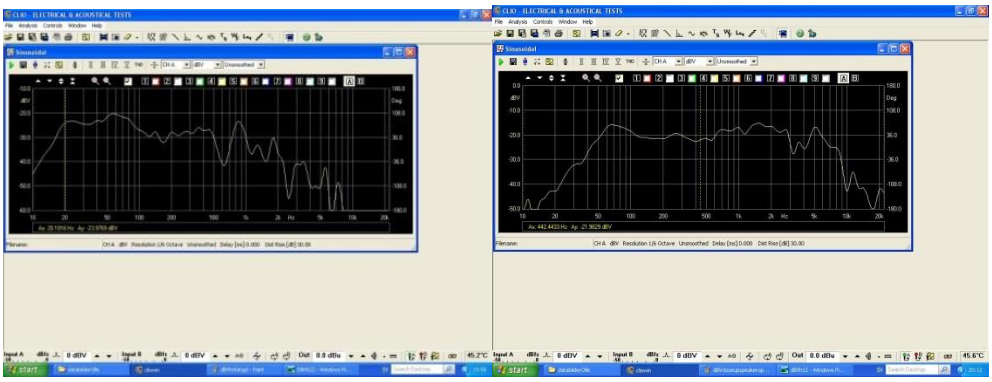

Figure 9. The plot to the left demonstrates a close-up measurement of the sound output amplitude from the vent, with the 27cm tube applied. The plot of the right shows the close-up measurement of the sound output amplitude of the cone.

4.3 Distortion

The results from our measurements of the distortion are shown for two types of loudspeakers. Figure 10 demonstrates the sound output amplitude for the closed-box and vented-box loudspeakers. The measurement for the vented-box loudspeaker with a 27cm-tube is done several times to demonstrate the difference between each run.

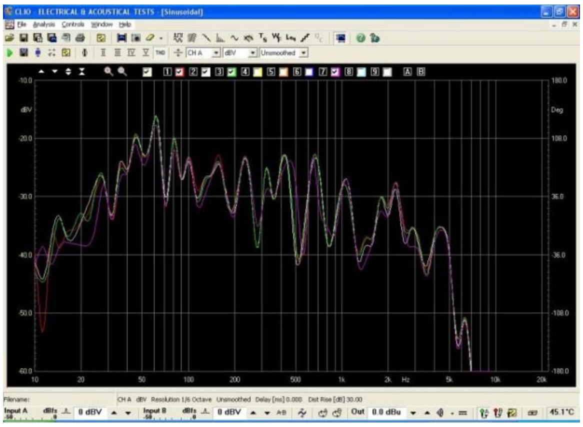

Figure 10. Distortion versus frequency. The pink line corresponds to the distortion of the closed-box loudspeaker, all other lines show the distortion of a vented-box loudspeaker with a tube of 27cm. The big number of lines of the 27cm tube demonstrates the variance between each run.

4.4 T&S parameters

The experimentally retrieved values of the T&S-parameters are seen in Table 1.

Table 1. Experimentally retrieved T&S-parameters.

F_S	$67.4451Hz$	V_{AS}	$14.5069L$	R_E	14.000Ω
Q_{MS}	4.7702	Q_{ES}	3.7324	Q_{TS}	2.0940
$B \cdot l$	$5.1581T \cdot m$	dB_{SPL}	82.7871	S_D	$0.0177m^2$
C_{MS}	$0.3327mm/N$	M_{MS}	$16.7381g$	R_{MS}	$1.4870\Omega_M$
C_{AS}	$1.04E-7$	M_{AS}	$53.60kg/m^4$	R_{AS}	$4762\Omega_A$
C_{MES}	$629.1147\,\mu F$	L_{CES}	$8.8513mH$	R_{ES}	17.8929Ω
R_{AT}	$10847\Omega_A$	R_{MT}	$3.3876\Omega_M$	M_{MD}	$15.4085g$
Z_{MIN}	13.9549Ω	Z_{MAX}	31.8928Ω	Z_{AVG}	18.8147Ω
η_0	0.1145%	L_{1kHz}	$0.4658mH$	L_{10kHz}	$0.2797mH$

4.5 Comparing sound of loudspeakers using different tube lengths

Comparing the sound qualities of loudspeakers using different tube lengths with the method described in section 3.4 results in the plot seen in Figure 11.

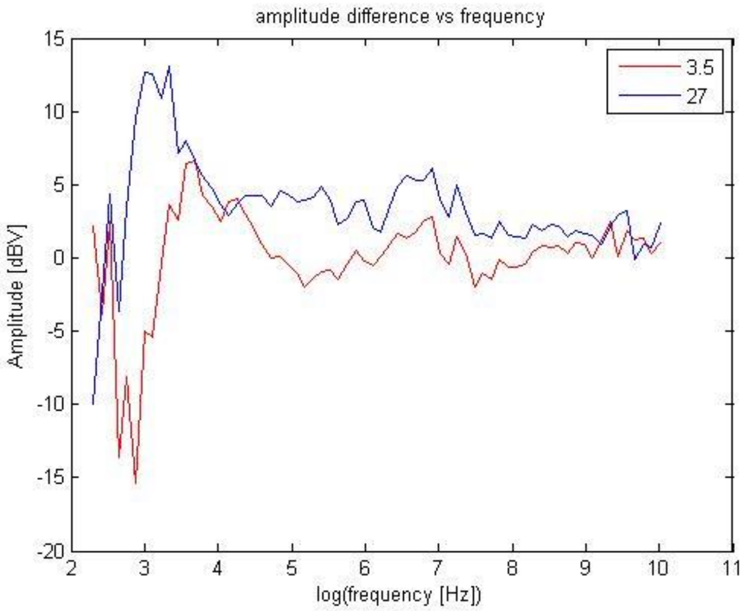

Figure 11. Sound output amplitude difference from a closed-box loudspeaker for the vented-box loudspeakers with tubes of 3.5cm and 27cm. The 27cm loudspeaker has a higher amplitude at lower frequencies than the 3.5cm loudspeaker.

5. SUMMARY AND CONCLUSIONS

The closed box loud speaker preforms well between 70 and 8000 Hz and has a resonant frequency of 67.4451 (see Figure 8 and Table 1)

The conclusion that can be drawn from the measurement of impedance of the bass-reflex systems shows that the tube that generated the curve closest to a ”perfect” impedance curve (see [2]) was the tube with a length of 3.5cm as seen in Figure 7.

But when comparing the amplitude of the sound at low frequencies it can clearly be seen in Figure 11 that the tube with a length of 27cm created a lower cut off frequency as well as higher sound amplitude in the lower frequency range. Since the one of the supposed advantages of a bass-reflex is to lower the cut off frequency the tube with length of 27 chosen as the best tube to redesign the system.

By examining Figure 10 the redesign system does not have a lower distortion than the original closed box system. The reason for this is unclear.

It can be seen in Figure 8 that the system with a hole of length 27cm does give a lower cut off frequency than the system with a hole of length 3.5cm and the closed box system but it does not generate smooth amplitude versus frequency curve. The smoothest amplitude versus frequency curve is given by the system with the 3.5cm tube closely followed by the closed box system.

By comparing the close up measurements of the amplitude of the sound coming from the vent and the cone (see Figure 9) we see that the sound coming from the vent lies in the low frequency range and that the sound from the cone lies in a higher frequency range as expected.

So all in all the redesigned bass-reflex system did lower the cut off frequency but did not have a smooth sound amplitude versus frequency curve nor did it have the expected impedance versus frequency behavior.

The equations used to calculate the length of the tube was too rough approximations to be of any use in this experiment. From inserting the values from Table 1 into Equation 1 and Equation 2 the length of the appropriate tube for the system was calculated to 11.2cm which is far from the experimentally obtained value of 27cm.

The biggest cause of error in this experiment was noisy surroundings with doors closing and people talking. Another cause of error was asymmetric tubes and rough measurements of lengths of tubes and the volume of the box measured with a ruler.

Worth noting is also that CLIOwin sometimes malfunctioned resulting in bad data. Restarting the program caused it to run properly again. Some of the data attained could due to this demonstrate faulty behavior.

A calculated error analysis is not possible because the computer did all the calculations. We considered running every test several times and taking the mean value and after that calculate a standard deviation. We did not do this since the error in this case only increased the amplitude of the sound so surely taking many measurements should generate a higher mean value than the true value. Instead care was taken to preform qualitative measurements in quiet surroundings.

REFERENCES

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2. http://www.hi-fiworld.co.uk 131129