In-Ear Monitors using VRT Transducers
A market survey

Intent

It is the intention of this document to do a small scale survey of the marketplace in regards to in-ear monitors (IEM) in order to determine the price range and performance variations of typical products. The idea is to determine what is the range of product performance and prices and what, if any, link there is between price and performance. It is also the intent to document how several devices are assembled and constructed to achieve the measured performance and, if possible, to determine the actual VRT devices in use.

Background

NJL is developing the expertise to manufacture VRTs. Traditionally these types of transducers were used exclusively in hearing aids. This market, however, would be extremely difficult to break into owing to its dominance by Knowles. A review of the IEM market has, fortuitously, uncovered the fact that the IEM market may soon eclipse the hearing aid market in terms of sales volume. For this reason, it is necessary to investigate the IEM marketplace in order to determine the needs of this market segment. It has been conclusively learned that the IEM market has an entirely different set of design criteria than the hearing aid market. This document will outline those differences and make recommendations regarding the future direction that NJL should take.

A total of nine IEMs were purchased:

0. *Lenntek model Pro Series - Price $200*
1. *Ultimate Ears model Triple-Fi 10 - Price $400*
2. *Shure model SE210 - Price $150*
3. *Etymotic model ER6 - Price $100*
4. *Ultimate Ears model Super-Fi 4 - Price $130*
5. *Shure model SE420 - Price $400*
6. *Klipsch model Image S2 - Price $50*
7. *Altec-Lansing model UHP-336 - Price $130*
8. *Creative Labs model Aurvana In-Ear2 - Price $100*

It should be noted that the prices shown are list prices and not purchase prices or street prices. Actual prices vary widely and even day by day. For example the Altec-Lansing models were sold on Amazon.com for $50 when I bought them, but a week later. Both prices are well under the list price of $130. In most cases these models are already obsolete in that they are no longer the latest models. The market offerings are changing extremely fast, a clear indication of how readily the models are being sold and new ones introduced.

Testing

Several types of tests were performed. The first was a listening test using an IPOD. The same selection of five songs was listened to on each device and the sound quality was rated from 1 (very poor) to 5 (superior).

Next the devices were measured in a real-in (Zwislocki) simulator which is intended to equalize the load and the response to that response which would be measured in a free-field. This is critical to understand since the response of these devices into a standard 2-cc coupler will be quite different than the response measured on the ear simulator. I would have liked to have measured the 2-cc response, however, I did not have a 2-cc coupler, but I did have an ear simulator.

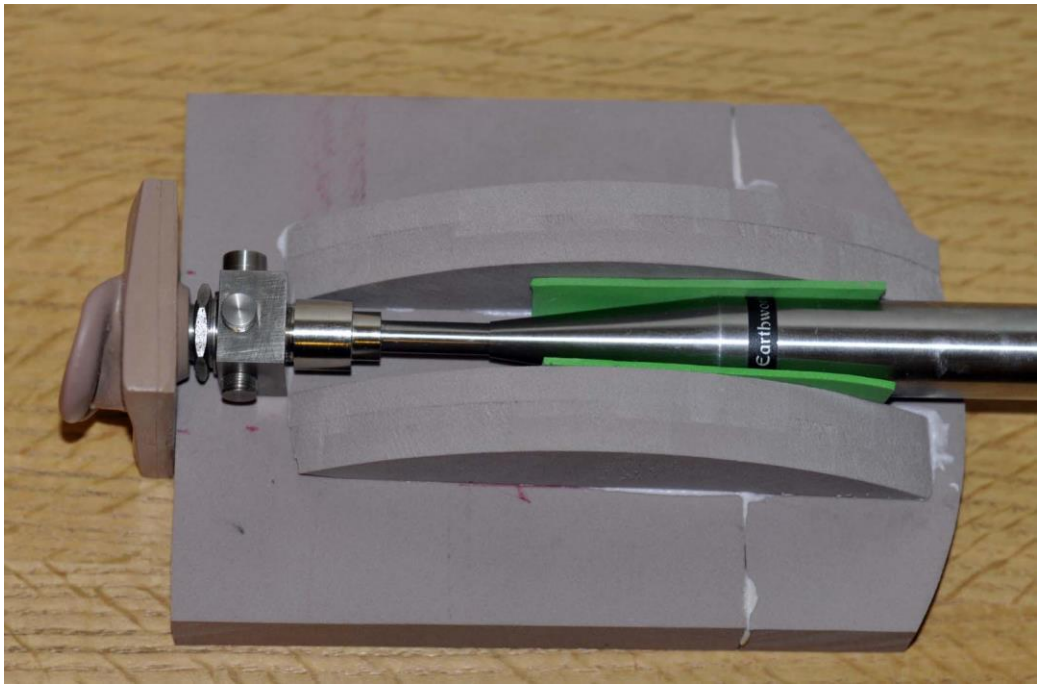


Figure 1 - Ear simulator and microphone system.

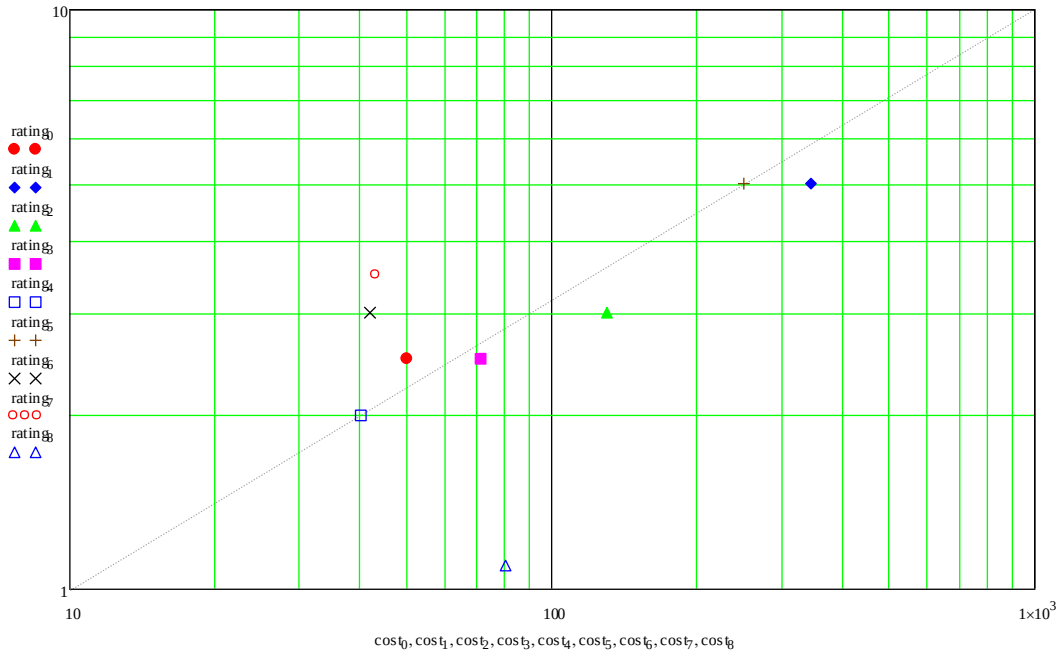
The impedance of the devices was measured as they are installed in the ear simulator.

Finally a frequency sweep was made at a standard SPL level in order to compare the distortion characteristics of the devices in an standard manor. The voltage required for this standard SPL would therefore vary widely since the sensitivities and impedances varied widely.

Sound quality versus cost

First a few words on sound quality. I do not feel that a thorough analysis of the sound quality was performed. I did the tests personally and I did them in a short span of time. In any subjective based test it is critical to use more than one evaluator and to perform identical tests multiple times. This was not done for the obvious reason of limited time. I felt that some sound quality data was better than no sound quality data, so I did "some". I did the subjective test before I did the objective tests. This means that I did not know beforehand what the actual performance was when I did the listening test. There are problems either way, subjective first then objective or objective first then subjective. After seeing the objective data I have serious questions as to the subjective data in a couple of cases. However, the overall trend is clear and I completely trust the end conclusions even though I do not trust a couple of data points.

Shown below is a chart which orders the data as the sound quality rating versus the cost (the price I actually paid in this case). The legend follows the same order as the list on page 1.



This is a most interesting chart because it shows that there is a very clear relationship between the price and the perceived quality. I used log-log axis here since on this type of plot the correlation line is very clearly seen to run from corner to corner. Points below this line represent products whose sound quality was not up to par and points above this line would indicate good value - above average performance for the price. The Creative Labs (8) data point indicates a dismal product and the Altec-Lansing (7) data point indicates a superior product. The Klipsch (6) appears to be a good value, but this is precisely the data point that I question, because the measured performance was dismal. Based on the objective data the Creative Labs should not be as low as it was. But all the other data points will be seen to have consistent subjective and objective performance in line with their price.

Based on this data it will be easy for us to position a product so as to be above the line and therefore offer an above average value to the consumer. Since any product that NJL would make will have to break into

the market with no brand recognition, it will be necessary to offer a better value than any of the competition.

One interesting note is that the Klipsch unit turned out to not be a VRT transducer, but was in fact a moving coil. That it rated high on the subjective performance is curious because it had very poor performance. This unit made it clear why virtually all IEMs are going to VRTs. In this application, moving coil transducers are clearly inferior as the data for the Klipsch will show. I'd like to understand why it did not turn out to have such a poor subjective response. One possibility is that I got the Creative Labs and the Klipsch mixed up in the listening tests since these two units look nearly identical. That mistake would then make *all* of the data perfectly clear.

Objective performance and assembly by unit.

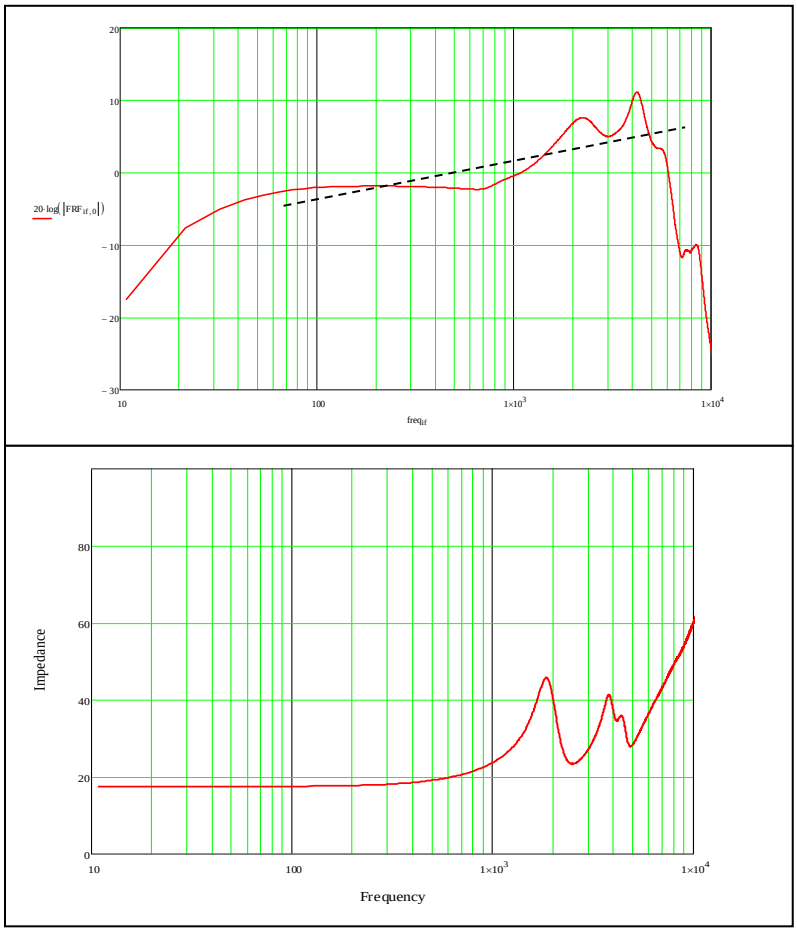
In this section the first graph will be the frequency response on a ear simulator. The second graph will be the impedance and the third graph is a log frequency tone sweep from 100 Hz to 5000 Hz. In the frequency response curves, 0 dB represent 110 dB SPL @ .1 volt, or 130 dB SPL at 1 volt. There is a low frequency High Pass filter in all of the data. This filter (in the mic preamp) was required to prevent extreme LF sound from overloading the microphone. Hence, the data below about 40 Hz is not valid. In theory, all closed ear systems, as all of these are, should go all the way down to very low frequencies.

In the frequency sweep plot the harmonics are seen as alternate lines sweeping upward at different rates. The first line is the 2nd order harmonic (but isn't always present), the 3rd the third order and so on. The higher the order the more audible and objectionable the distortion will be.

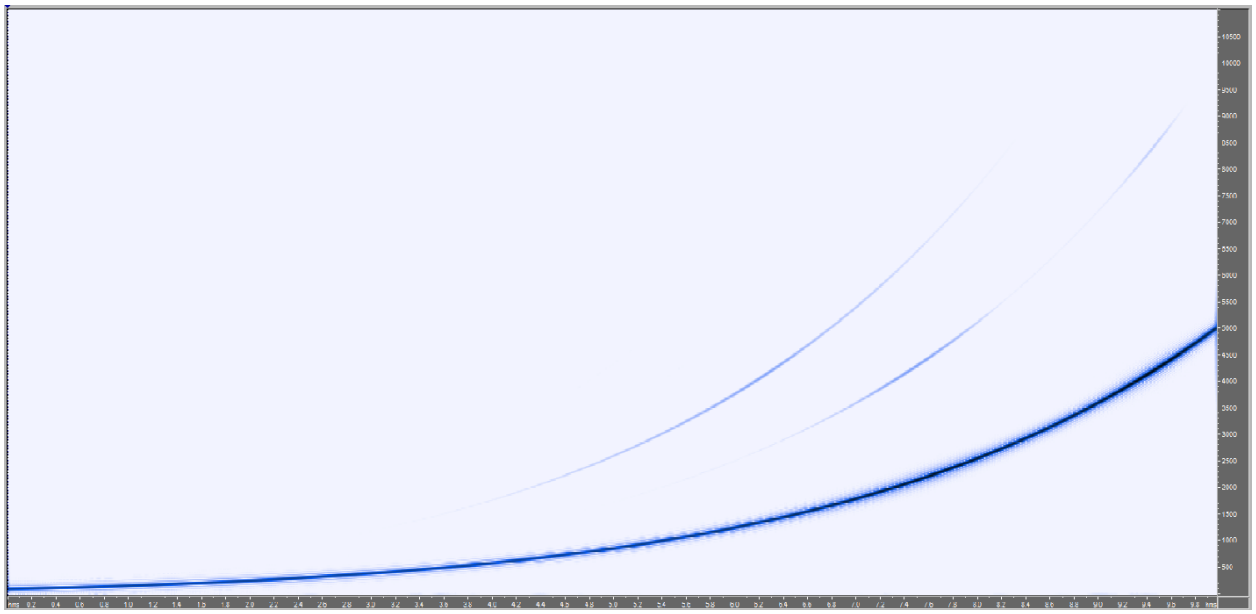
Photos of the ear piece and its disassembled construction follow the data. The specific transducer and its serial number is always shown. Comments on notable aspects of the specific design are made.

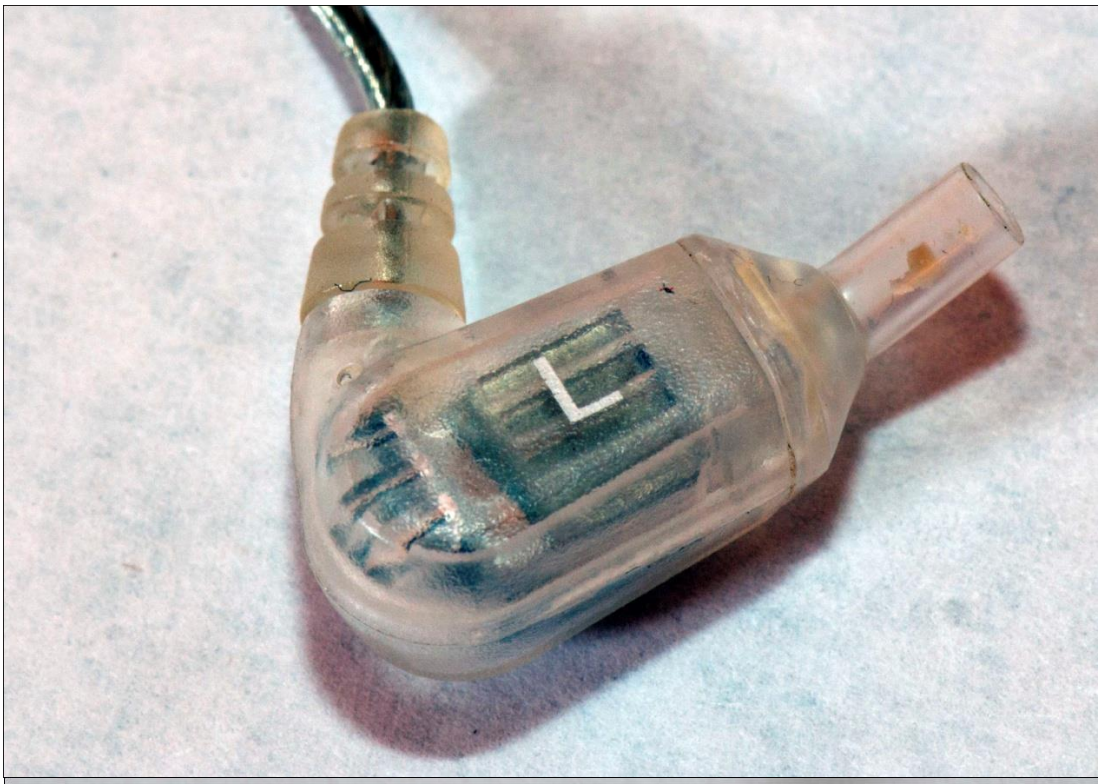
Lenntek

Frequency response and Impedance



The distortion of the Lentek is quite admirable, but the frequency response is not very good. It has a highly tilted upward average slope - see dotted line - at about 6 dB / oct. (more on that later). We will see that a slight average upward slope with a shallow vally at about 700 Hz appears to be the best overall response. The Lenntek has a very nice case4, but is otherwise an average design.

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lenntek


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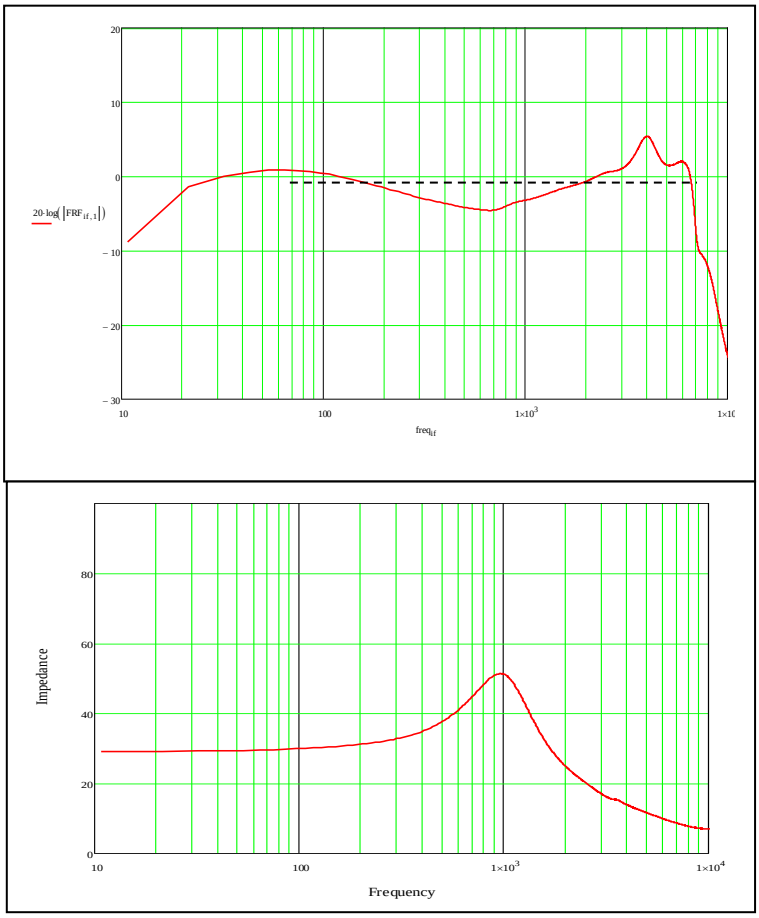
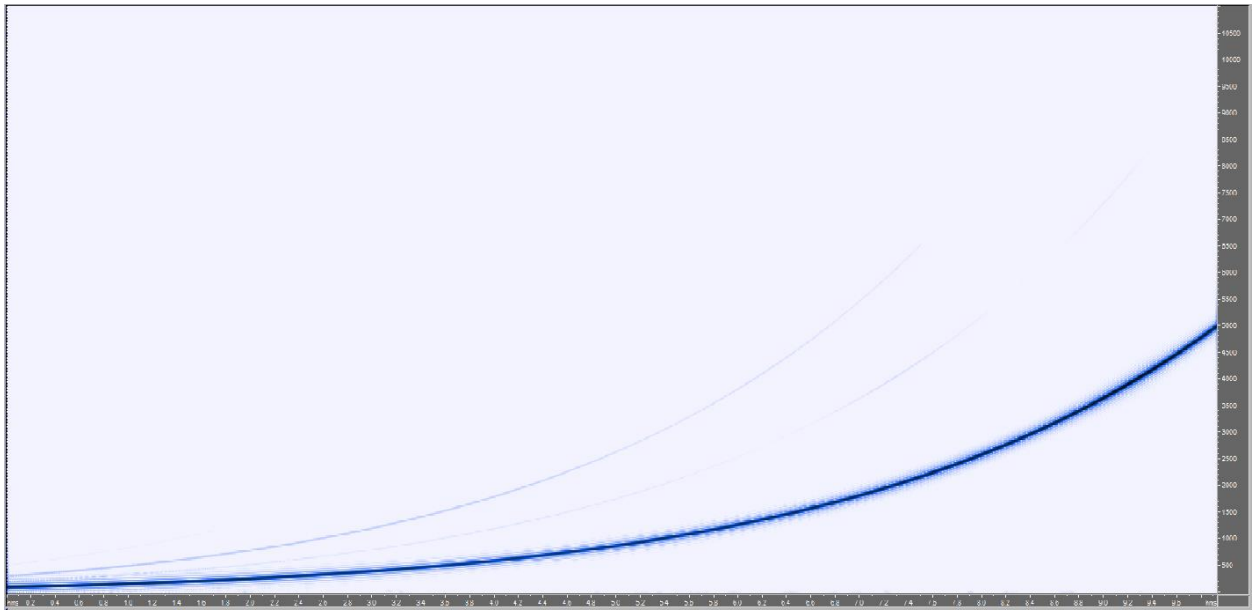
Ultimate Ears Triple-Fi 10

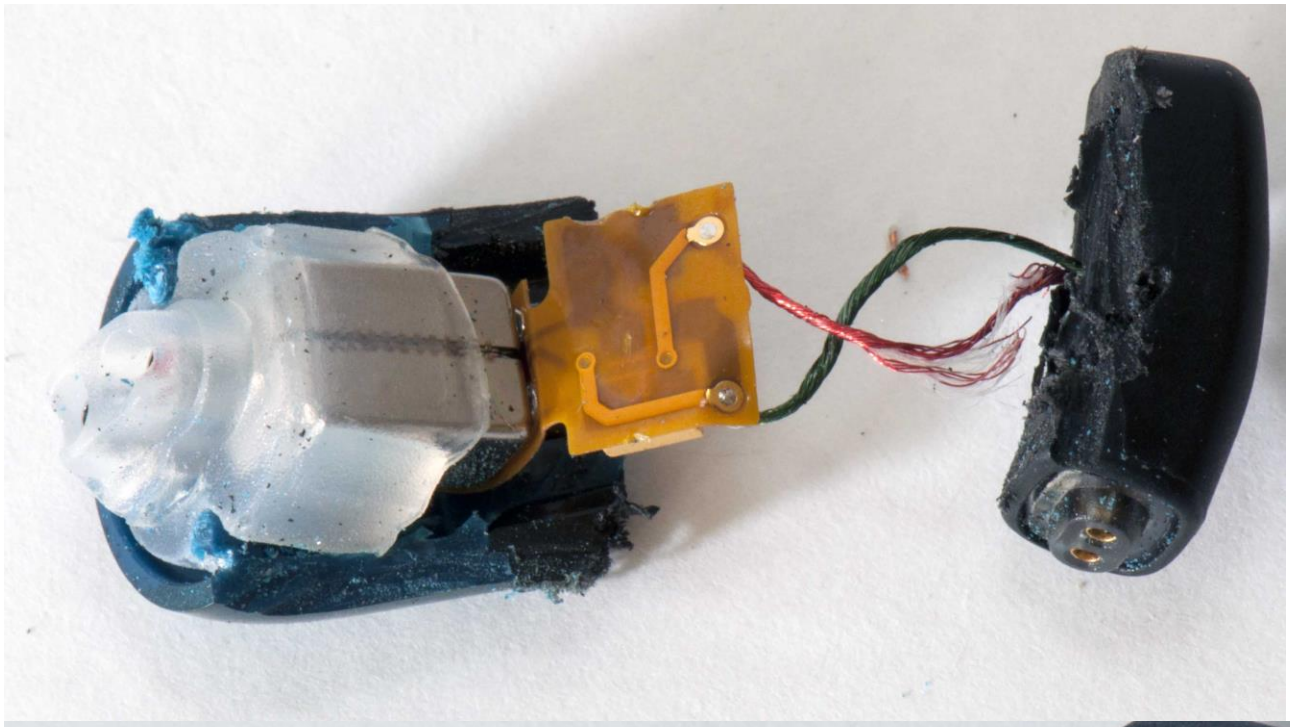
Frequency response and Impedance

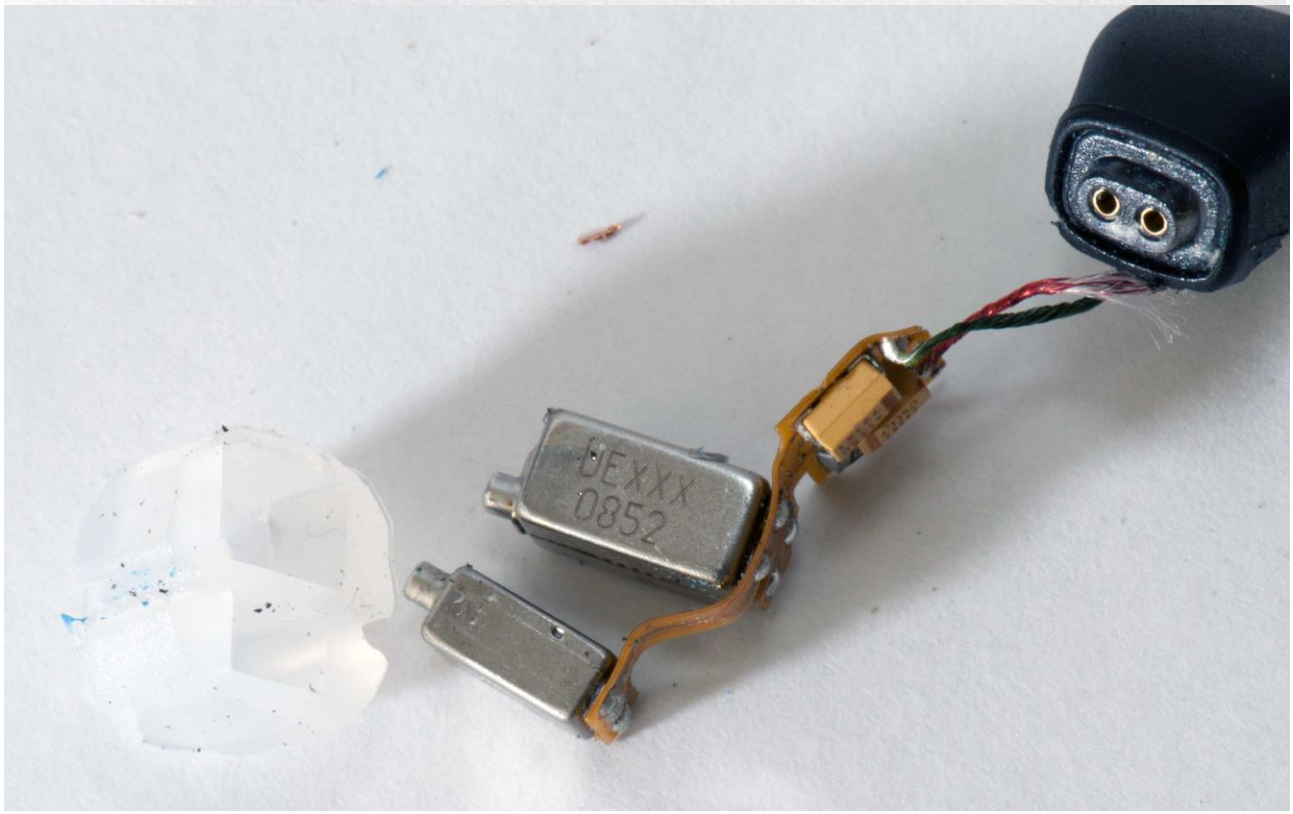


This device is one of the very best products in terms of sound quality. The response is very good with an almost completely flat response and slight valley shape. The slight peak at 4 kHz appears to be desirable since all good units have at least a small peak here. It appears that better damping is desirable. It also appears that a trough like response is desirable, with nearly equal peaks on each side of the trough. The distortion is exceptional being virtually non-existant.

The design is quite interesting with two ports and a dual VRT bass unit. Both units have dampers as can be seen in the photos. An electronic circuit is also evident.



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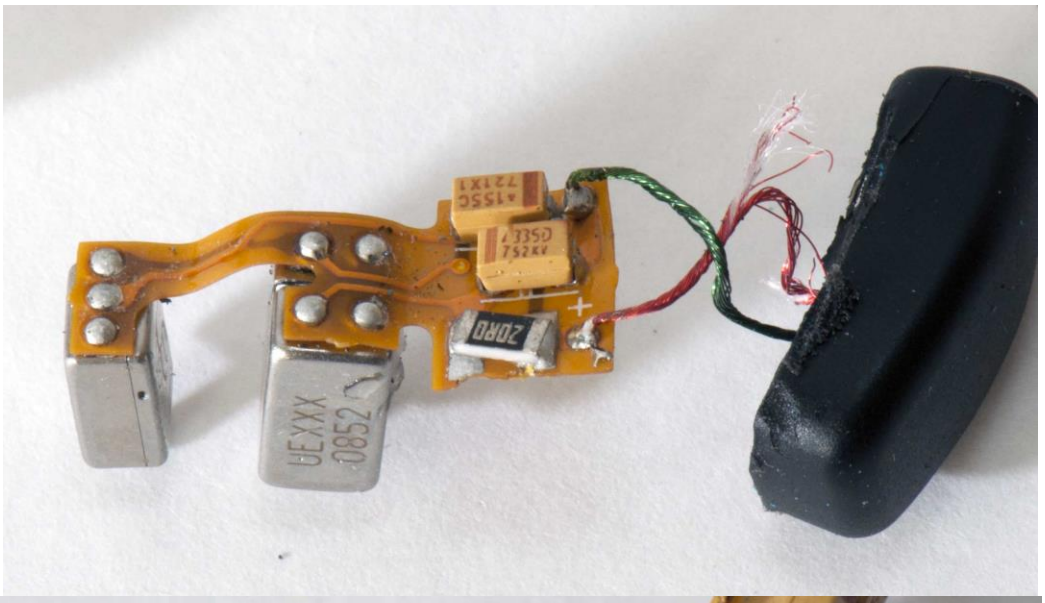
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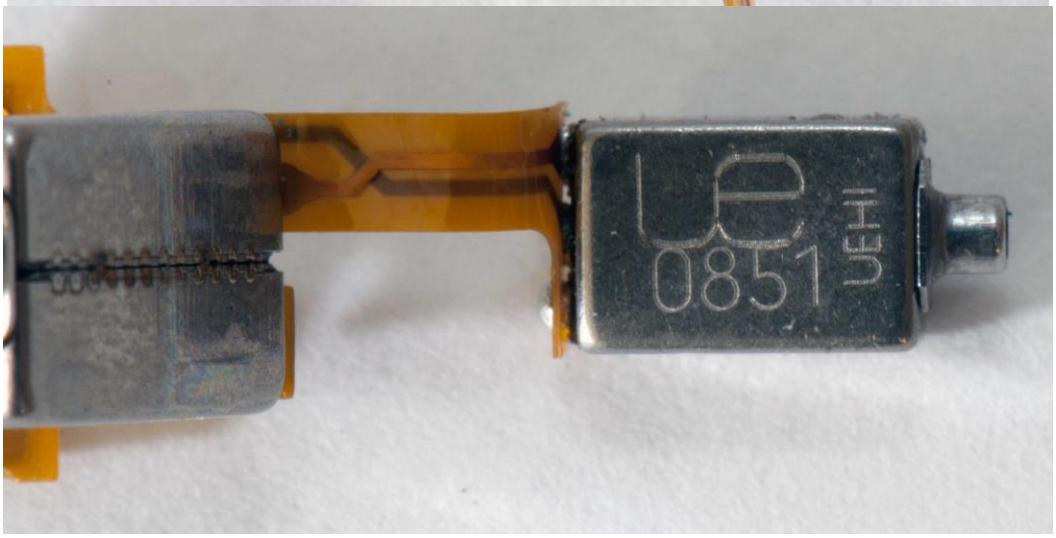
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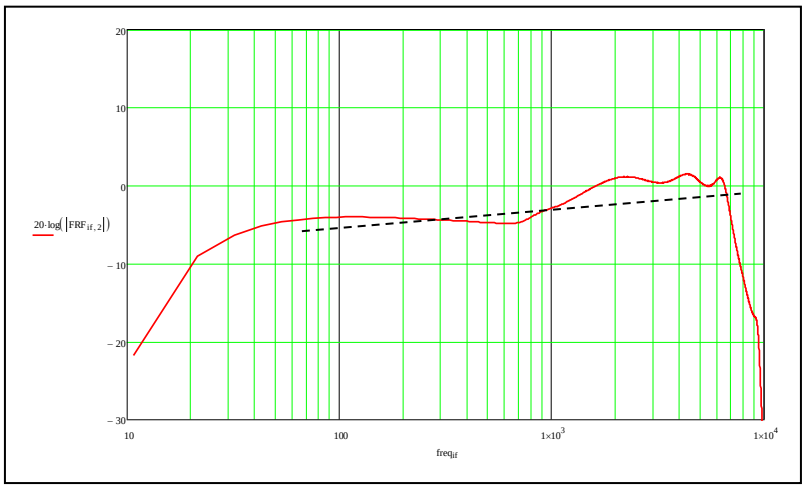
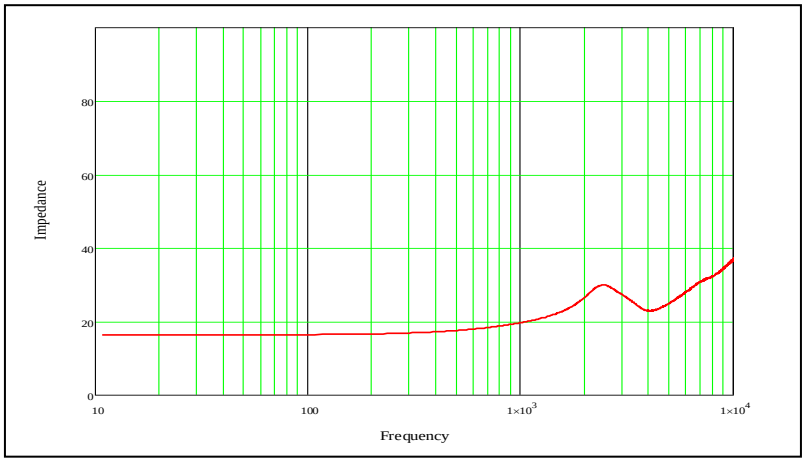
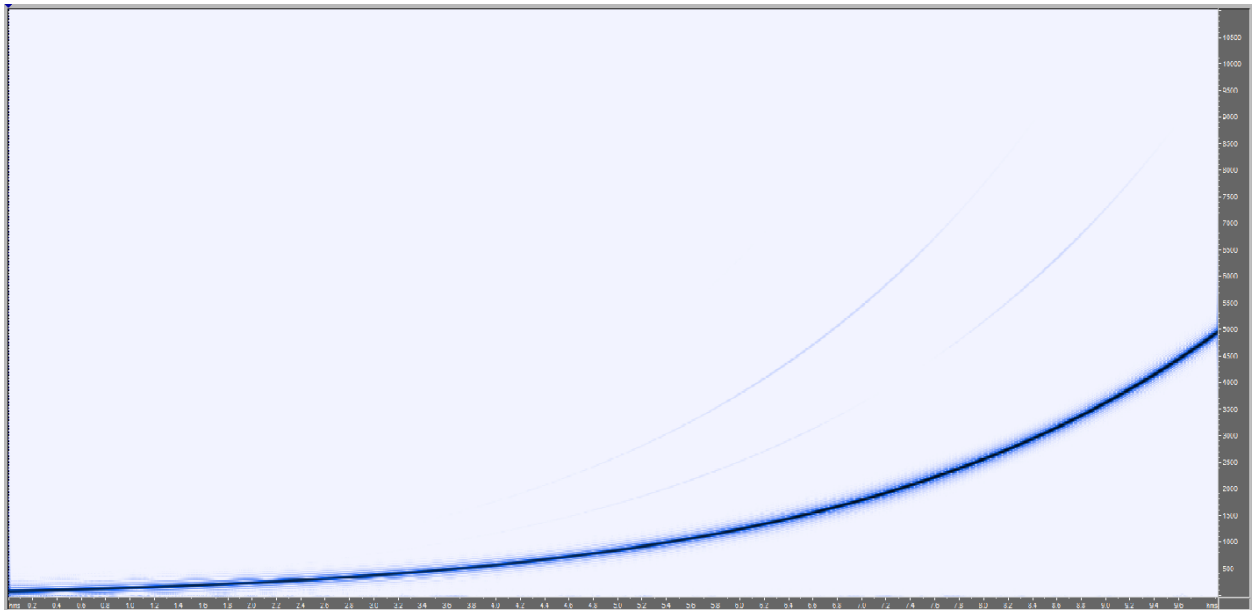
Shure SE210

Frequency response and impedance

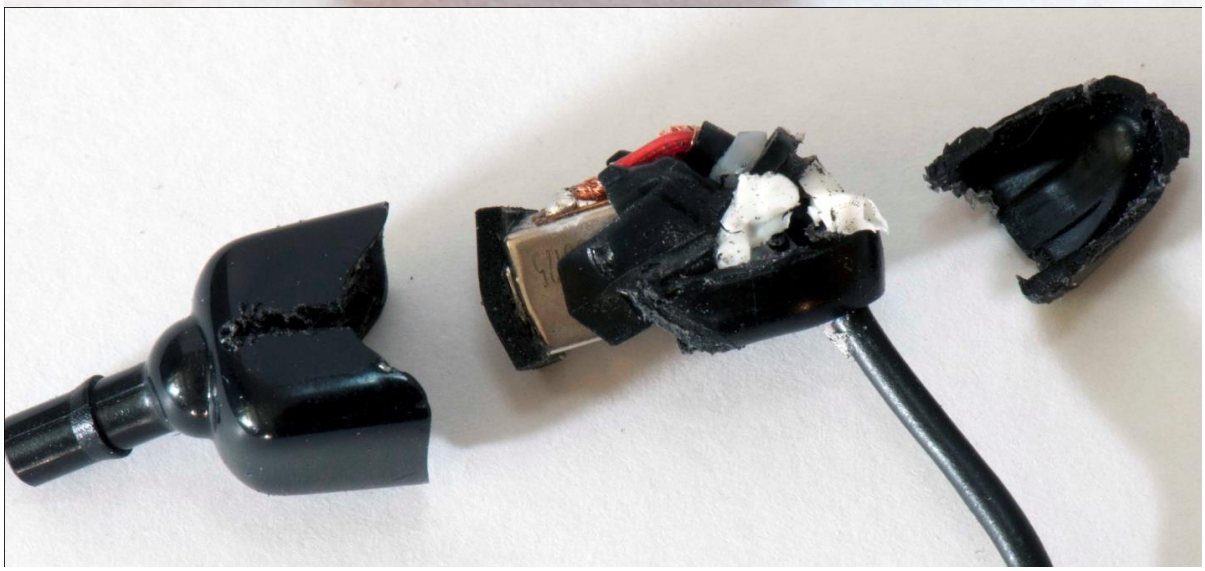


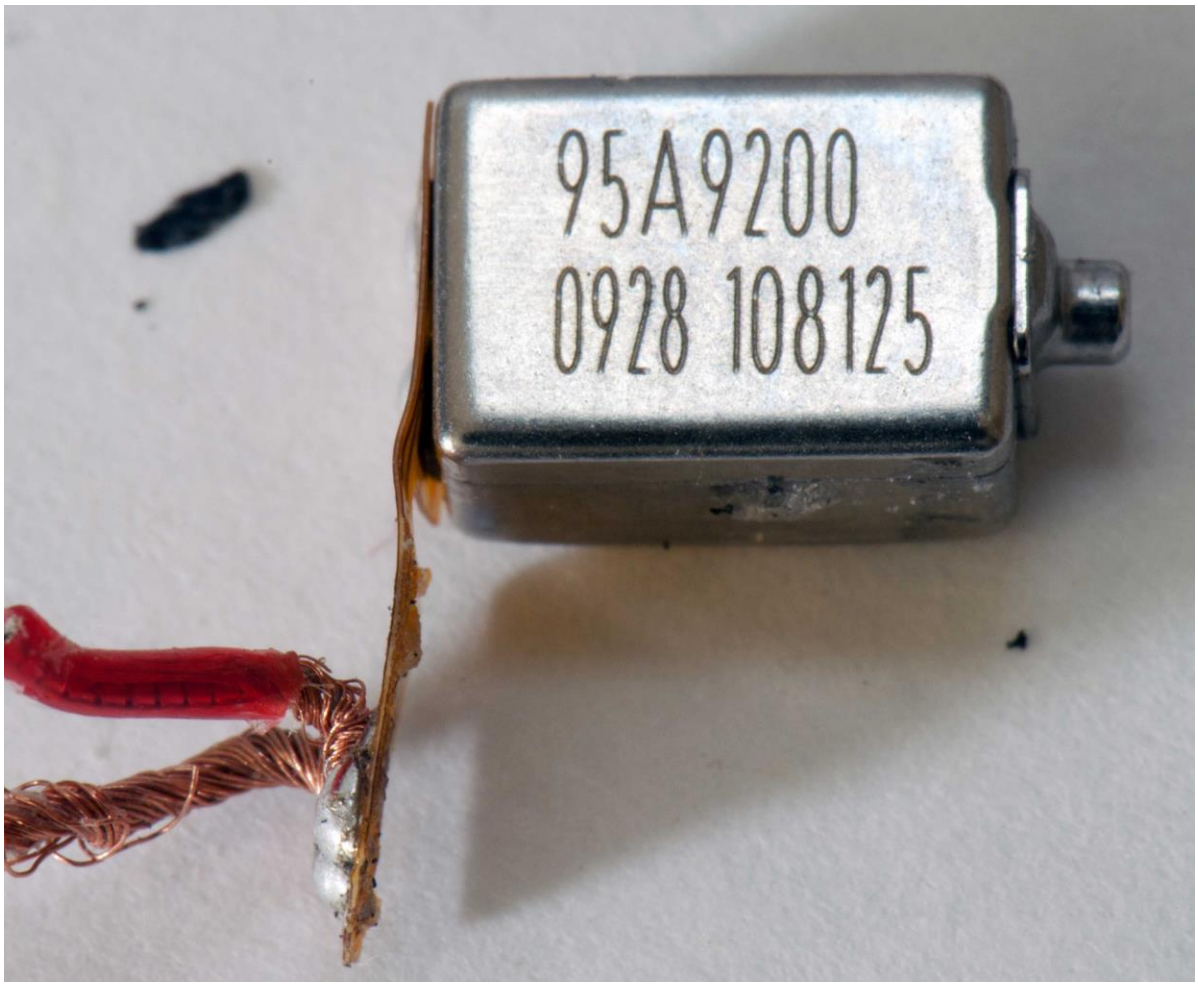


This response is again very good with a small HF rise of about 2.5 dB/oct. There is only a small trough effect and the HF peak is very well damped. The distortion is also quite good. The overall design is fairly standard.




SHURE

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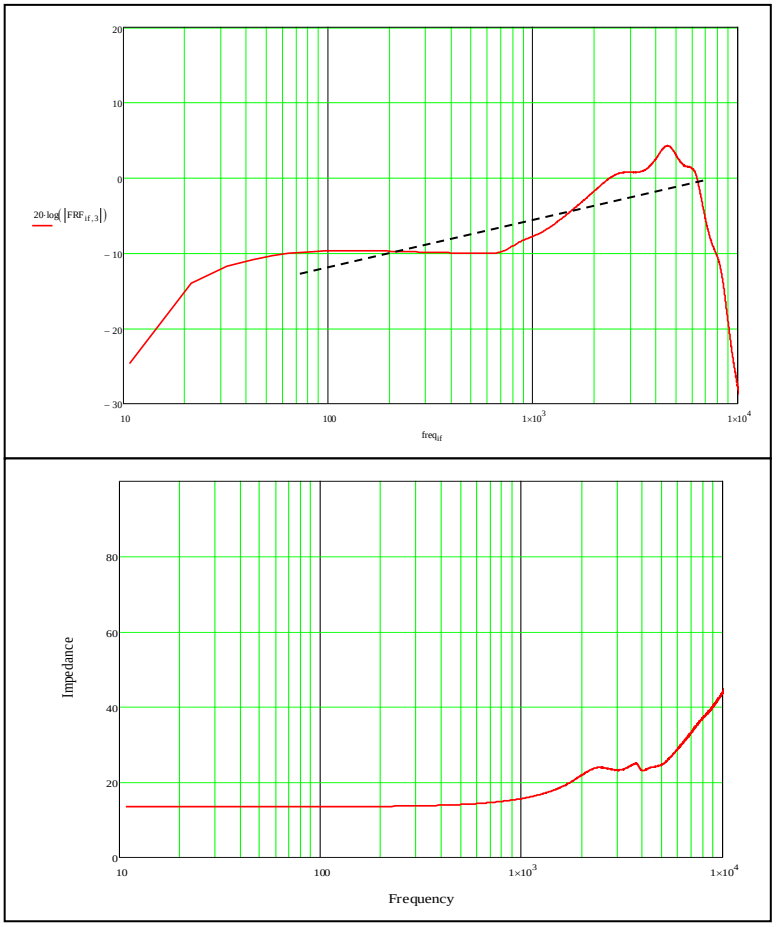
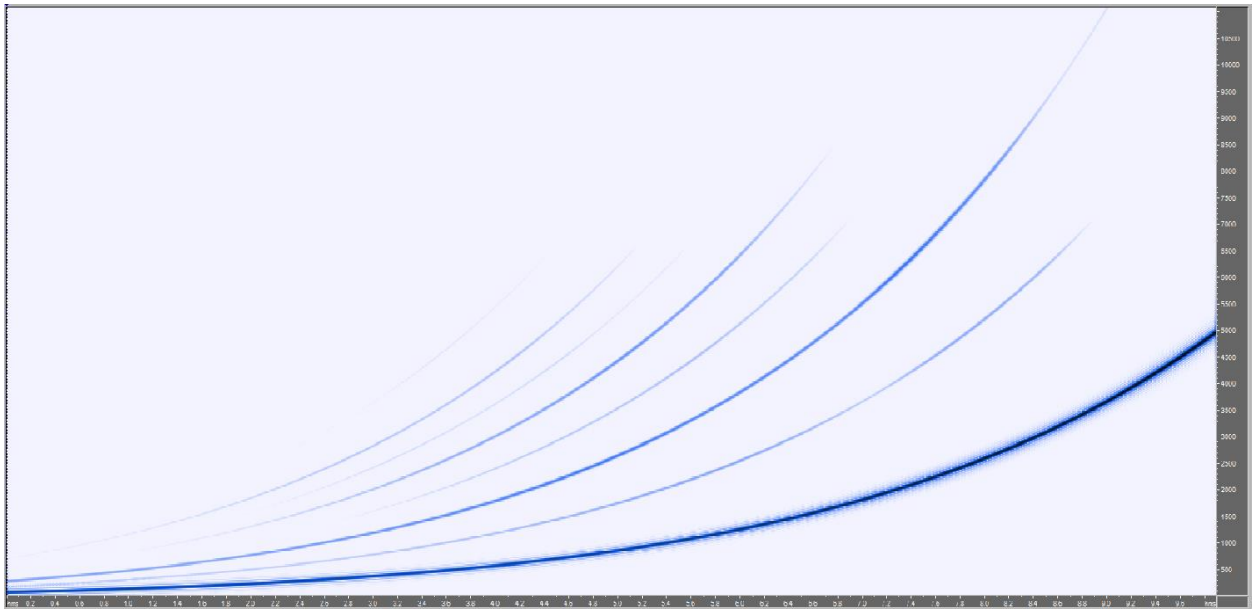
Etymotic ER6

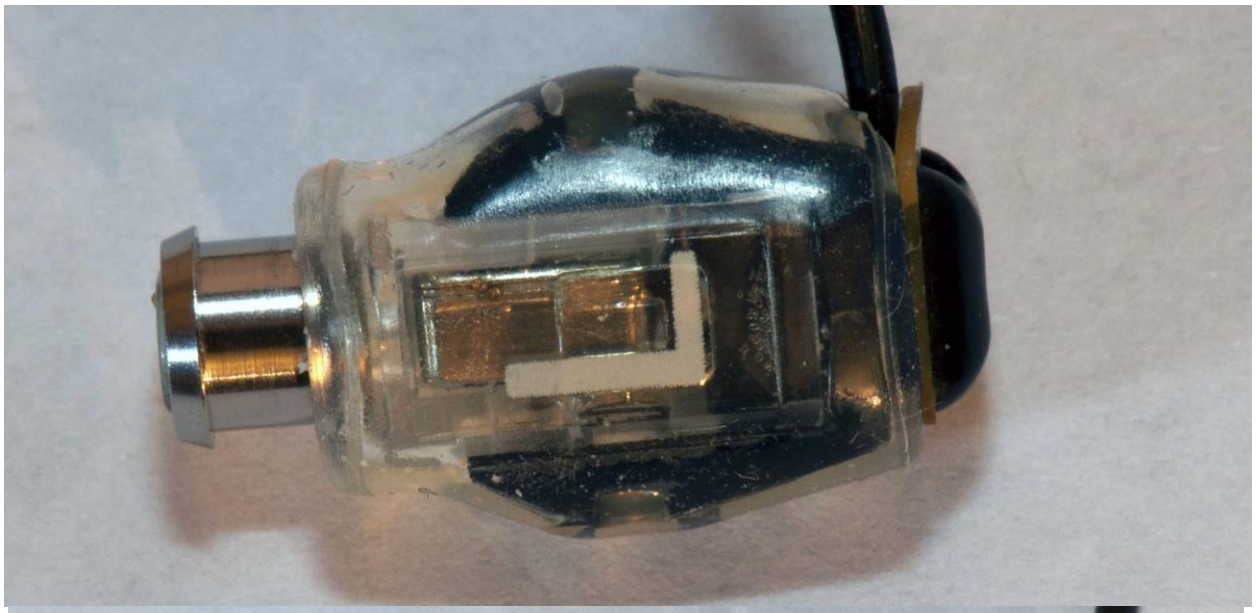
Frequency response and impedance

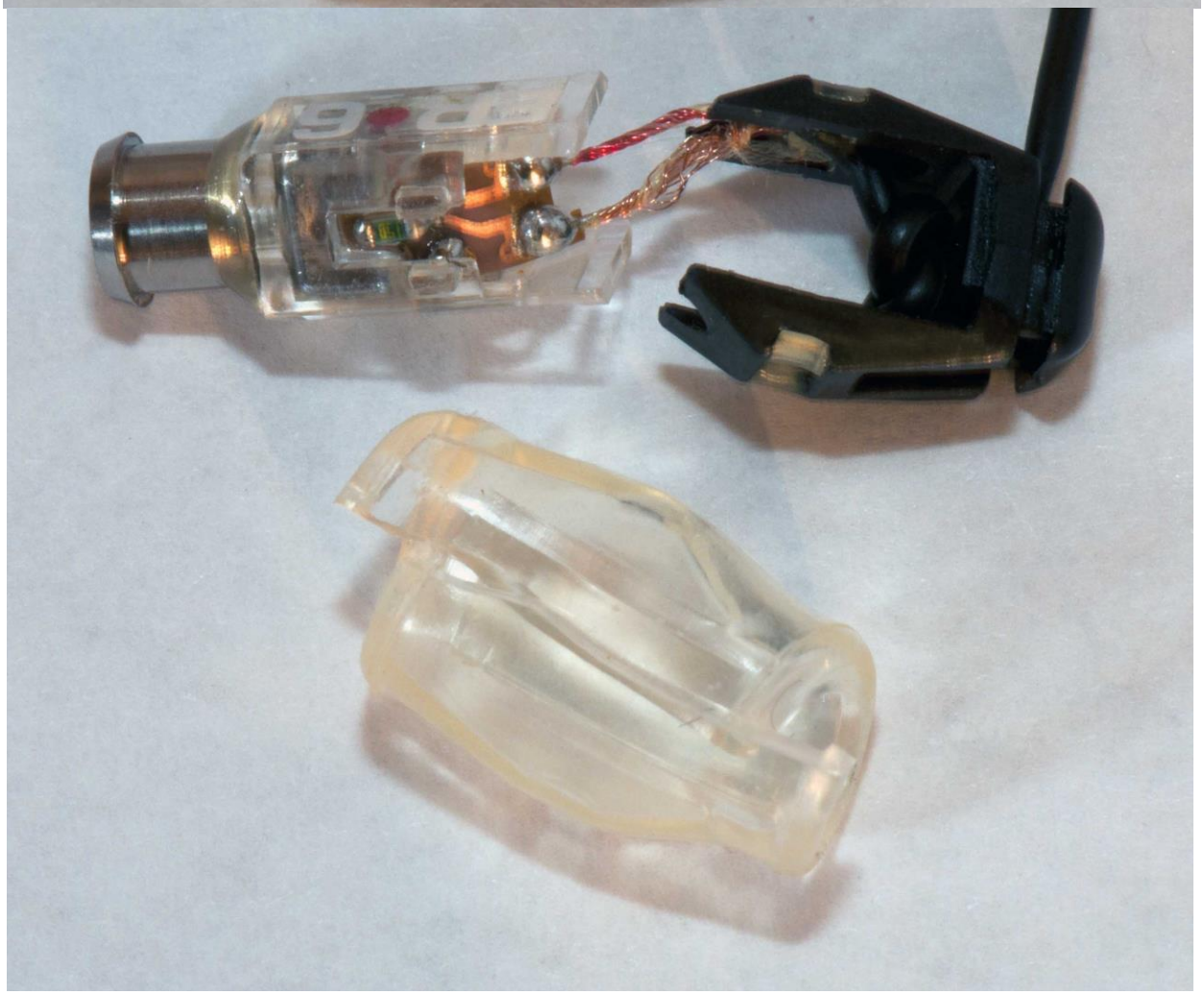


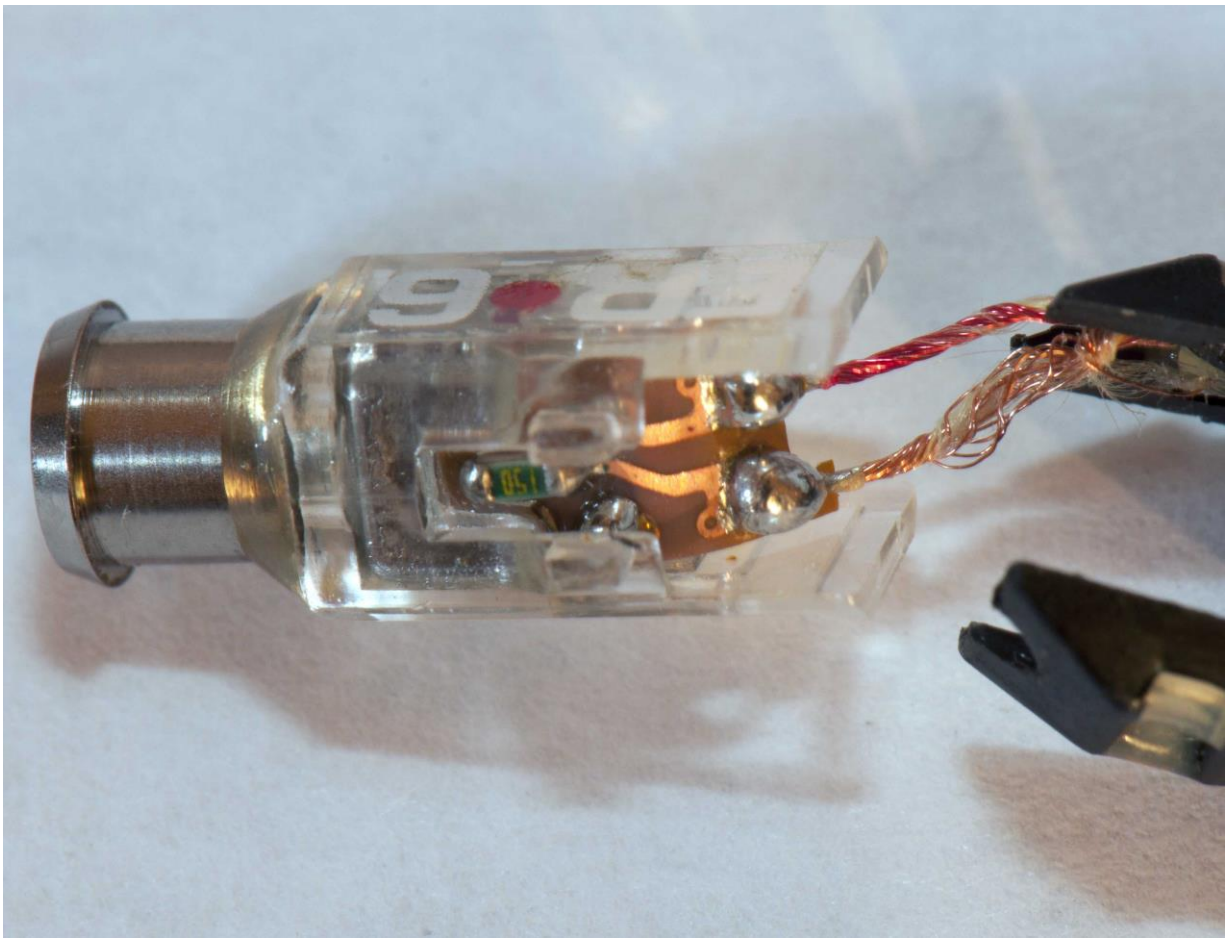
The Etymotic is a very simple construction but has a frequency response that is pretty poor being highly tilted upward at about 6 dB/octave. This unit is basically the first IEM to use VRTs. It was believed at that time (mostly by Mead Killion) that this rising response was necessary for a "natural" sound. The marketplace does not appear to believe that anymore.

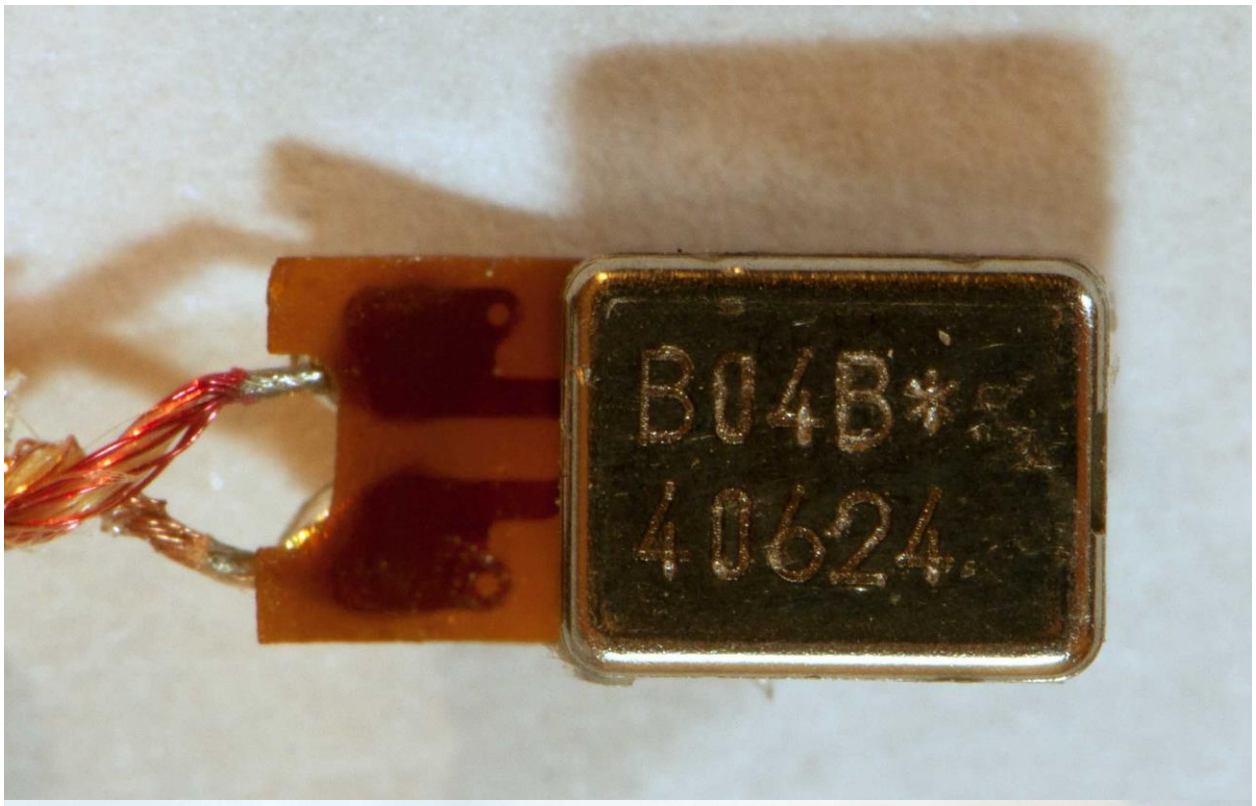
The distortion from this device is very bad, perhaps explaining why the subjective rating is so poor. The VRT does not has a port tube, and it has some kind of component on a circuit board. The reason for this additional component is unclear.







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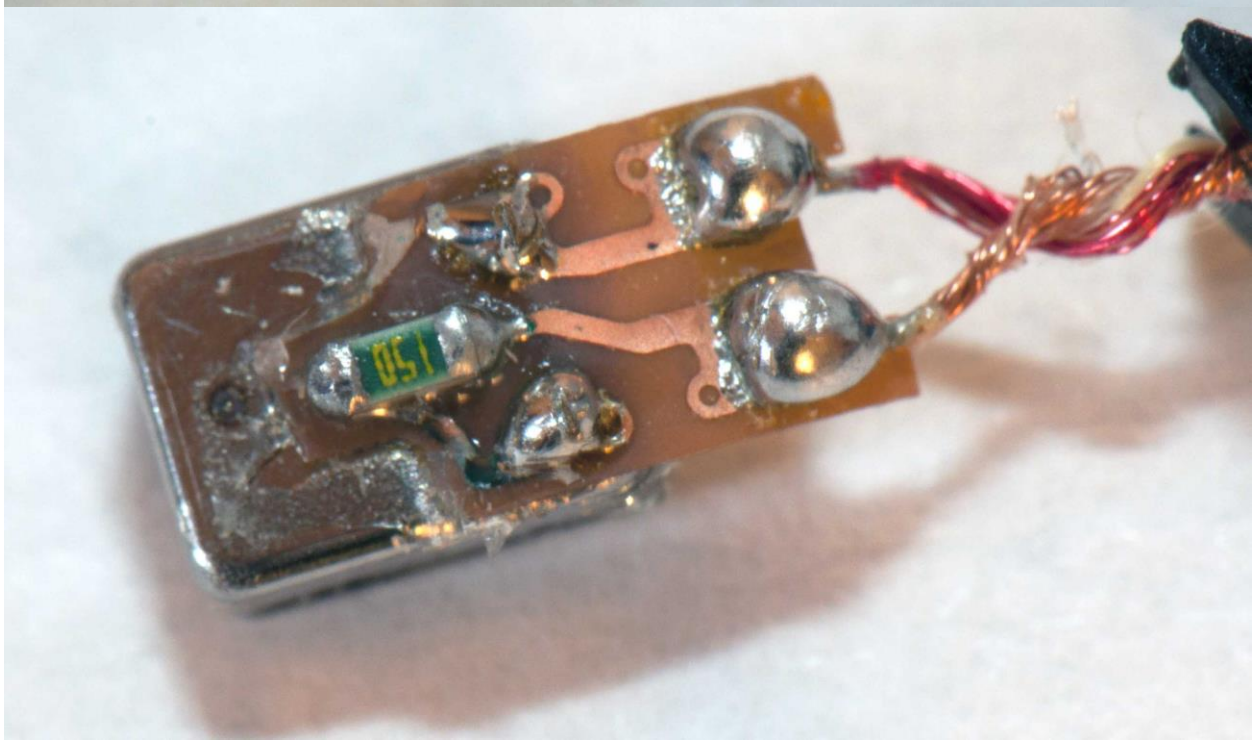
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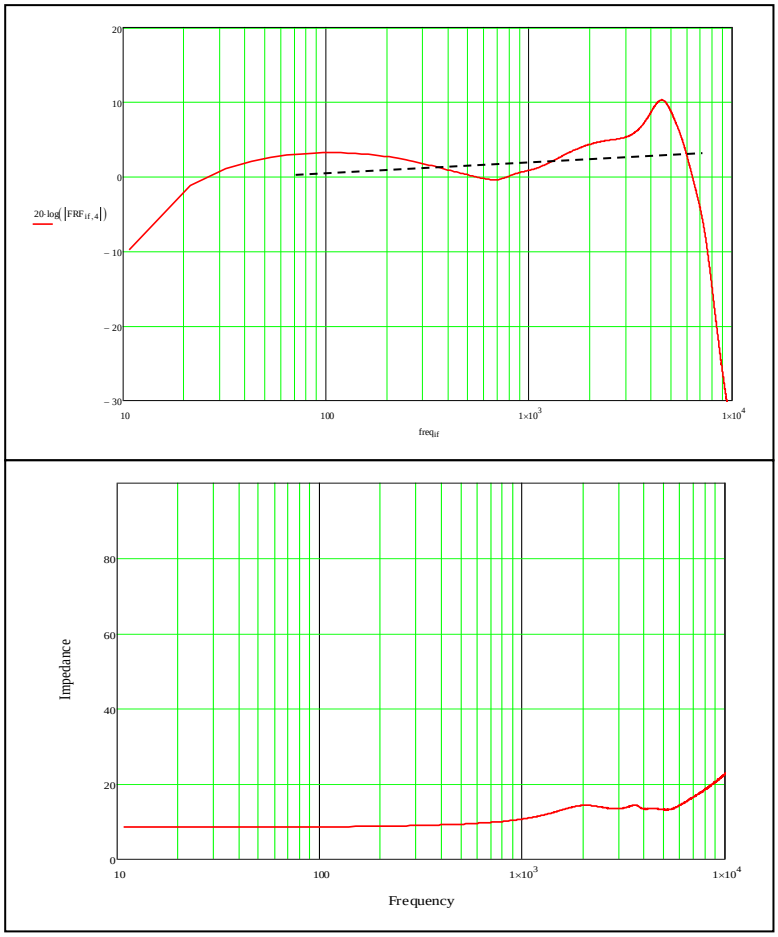
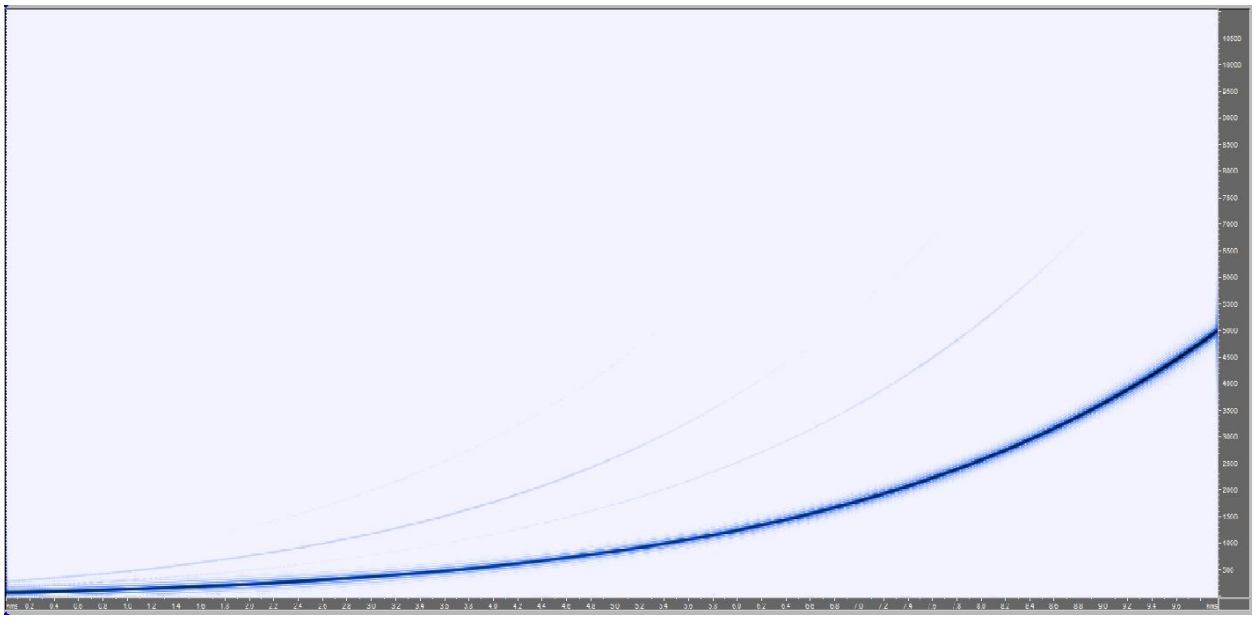
Ultimate Ears model Super-Fi 4

Frequency response



The Ultimate Ears design is very attractive and the construction quite appealing because of its simplicity. The case screws together. The response is very good being tilted upward at about 1 dB / oct. The resonance at about 4 kHz appears to be a little well damped by using a port damper. The basic vally shape is nearly the ideal. The distortion is extremely low. Overall this is a very good device.

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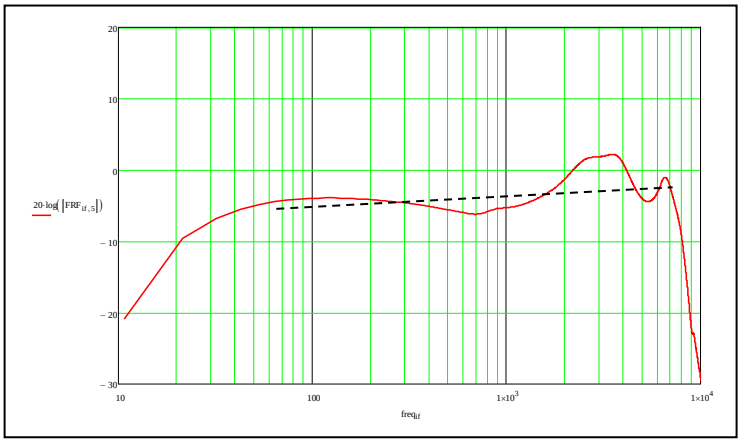
Shure SE420

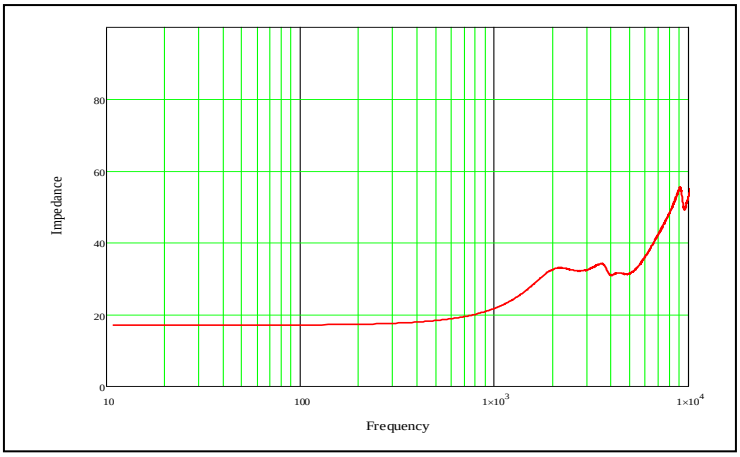
Frequency response

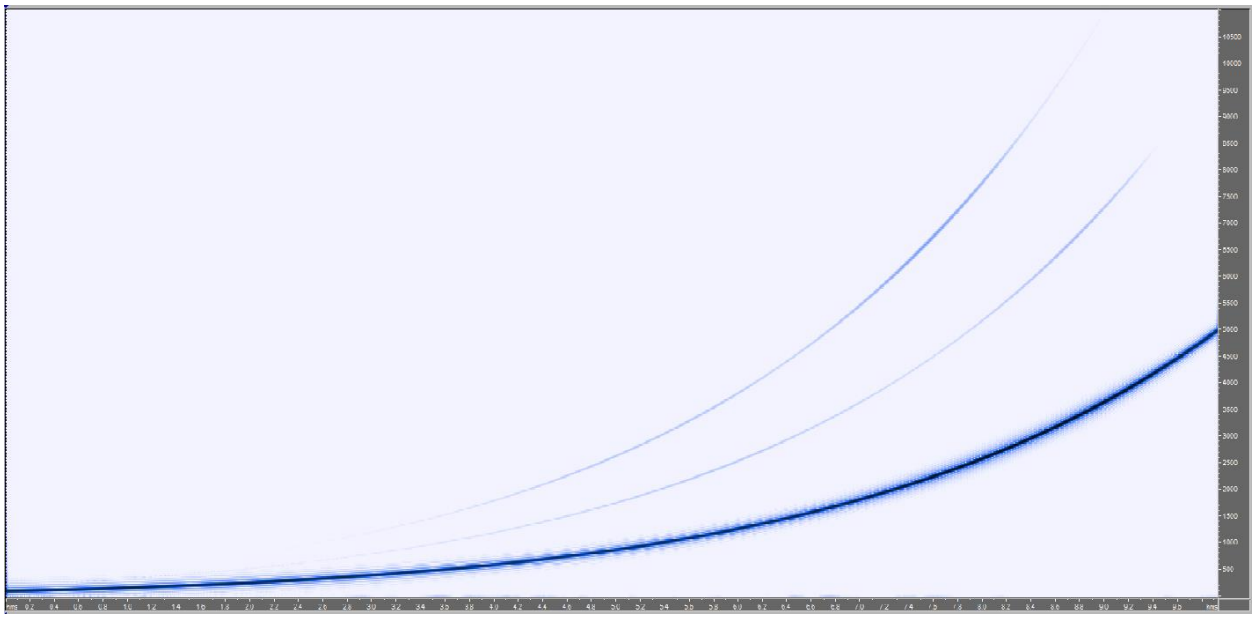


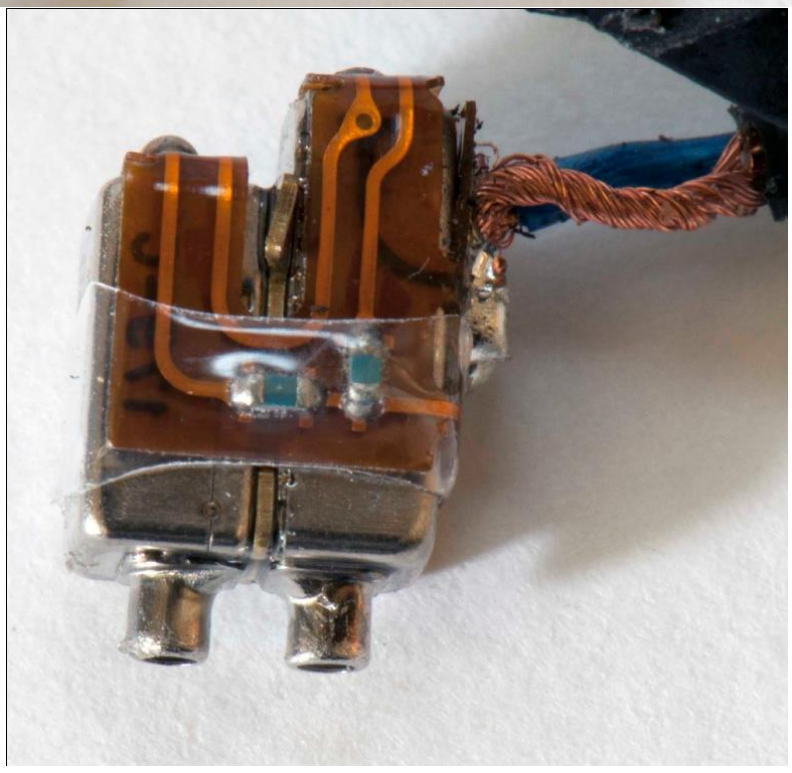
Th Shure SE420 response is exceptional, tilting upward at about 1 dB/octave. The resonance at about 4 kHz is well damped and there is an extension of the HF response from the use of a second VRT. The basic vally shape is readily apparent. This was ranked as the subjective best unit.

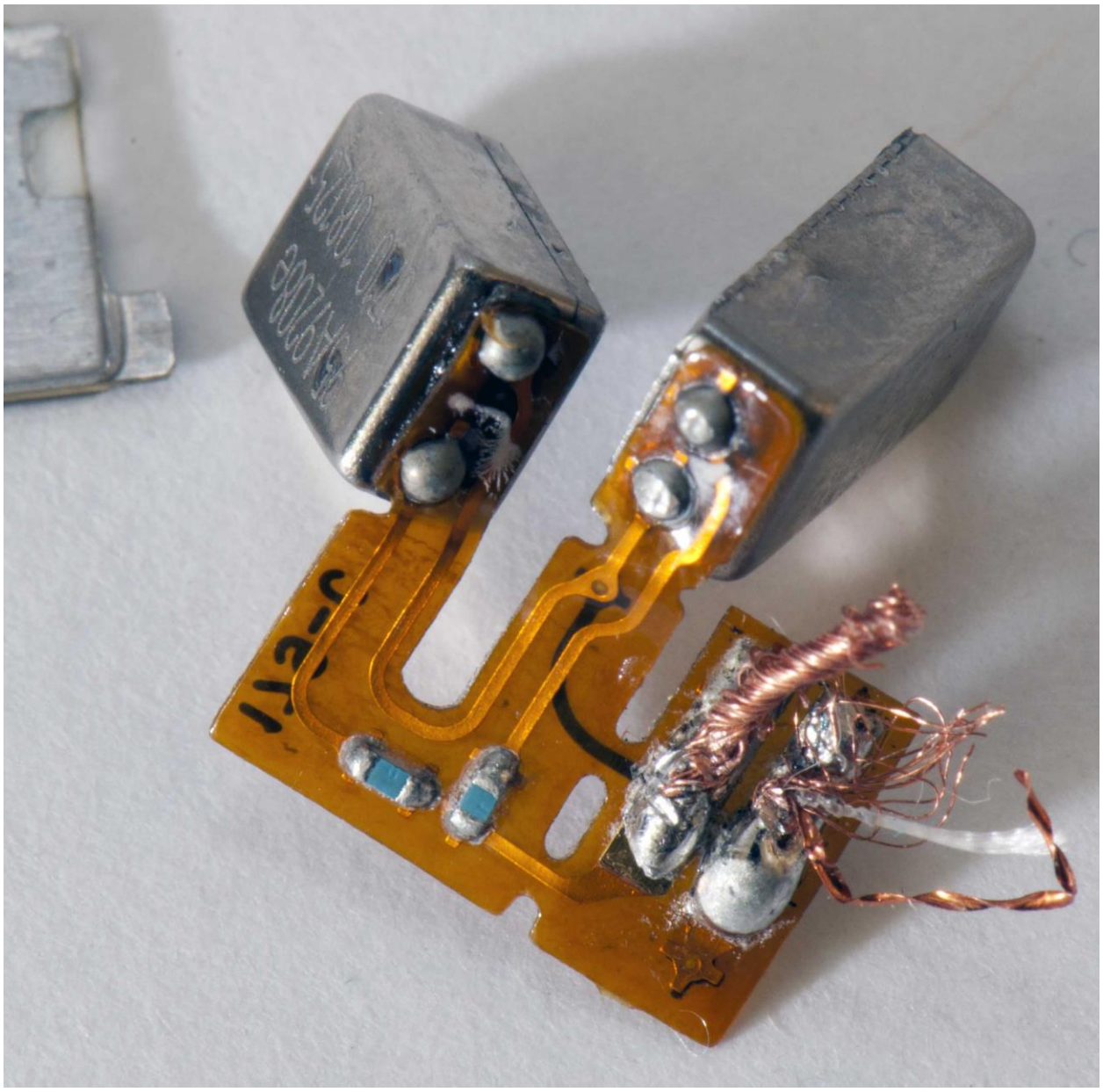
The distortion is surprisingly high for such an expensive device.

The construction is rather complex, but the dual transducers are readiliy apparent in the photos as well as the crossover network







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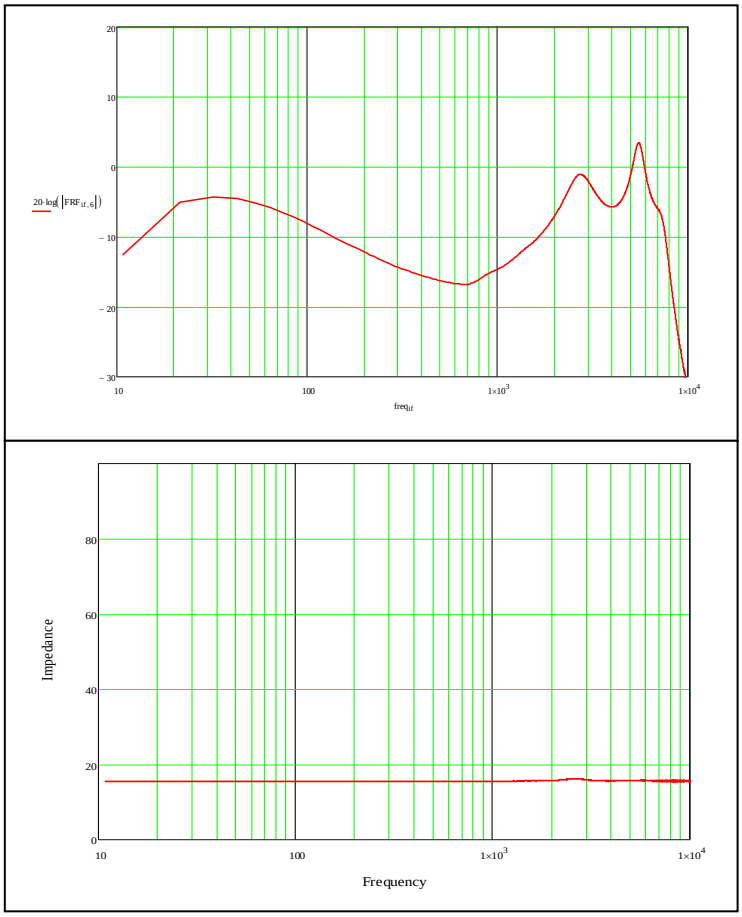
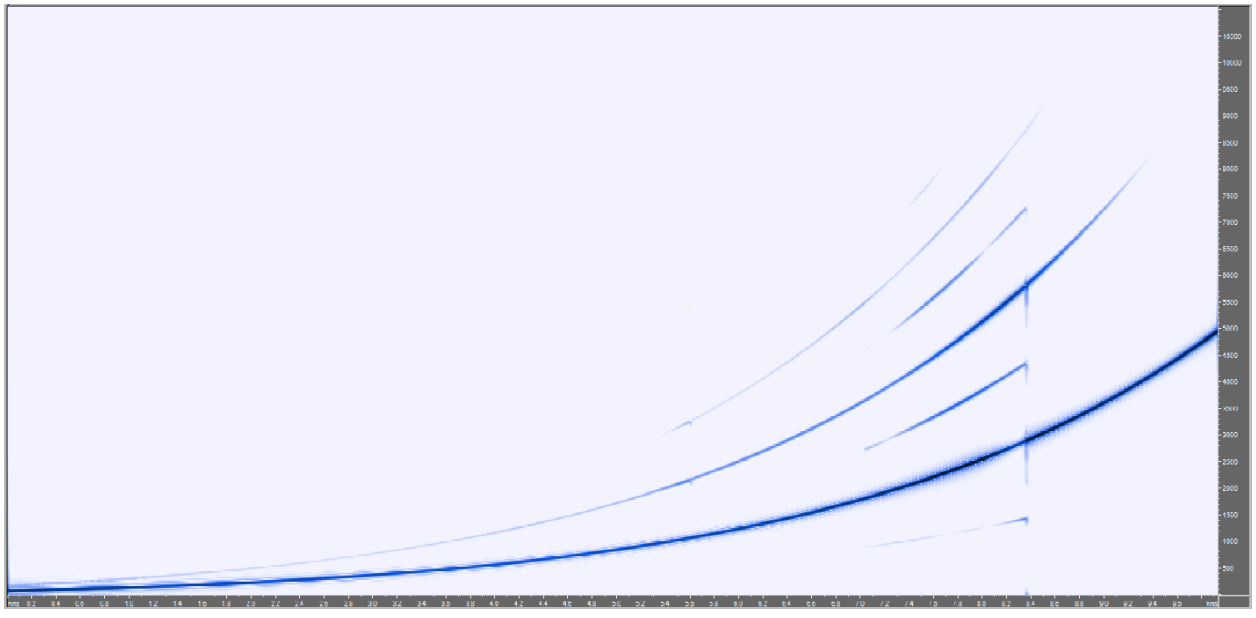
Klipsch Image S2

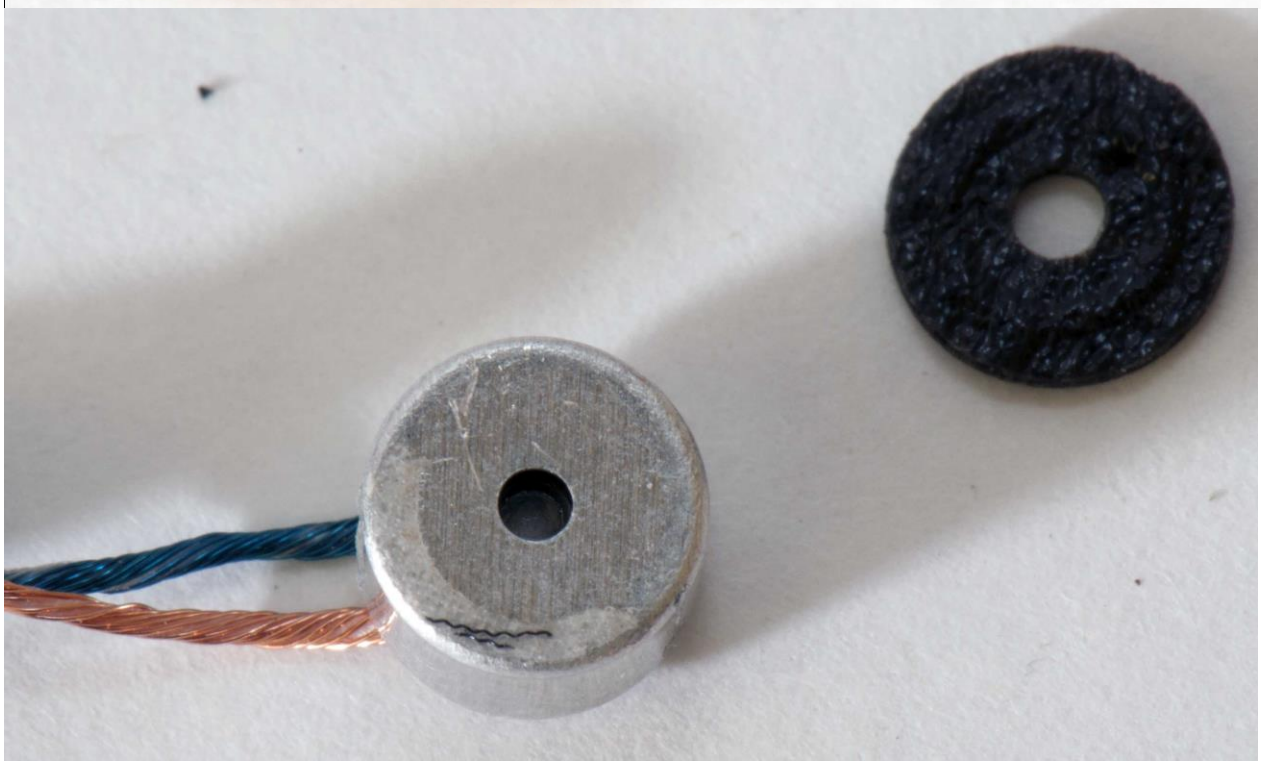


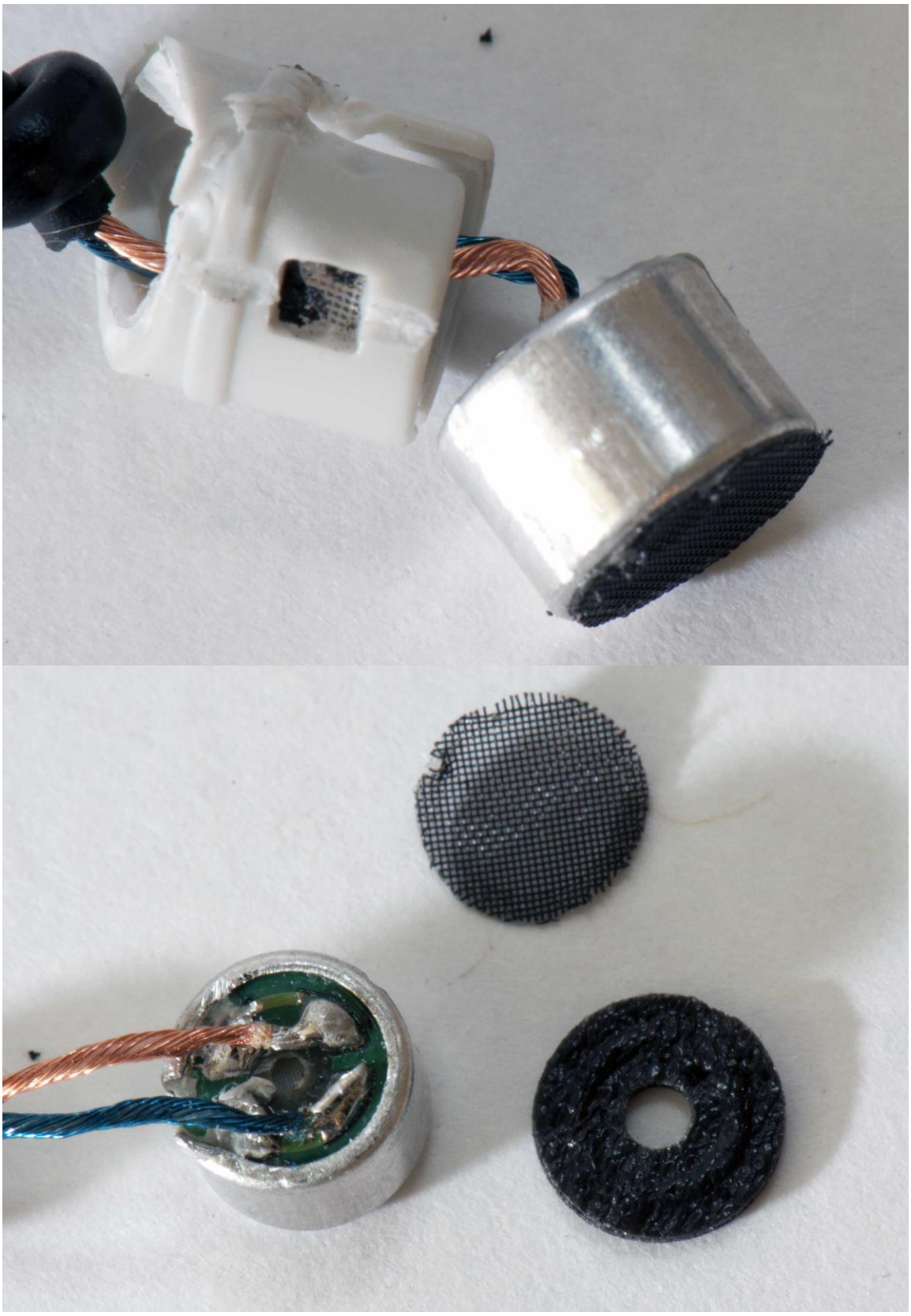
Frequency response

The Klipsch is unique in the set of devices tested hear because it is not a VRT. But this gives a very good oportunity to compare classic moving coil designs to VRTY designs. It can be seen that the moving coil is inferior in this application in every way. The response is very poor as the vally shpe is far too pronounced even though it only, tilts upward on average at about 2 dB / octave., which is reasonable. The sensitivity in the mid-band is extremely low. This extremely low sensitivity can be seen to be a serious problem in the distortion tests which are exceedingly bad. In fact it appears that the device went complety unstable during the sweep test at about 2500 Hz, or the drivers fundamental resonance. It is hard to believe that this device got a high subjective rating (I believe that a mistake was made). The resonances at about 4 & 6 kHz is are far too low damping.



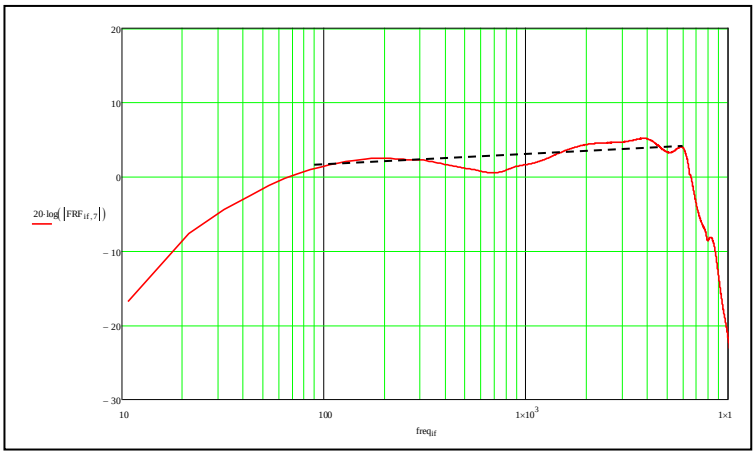

Klipsch

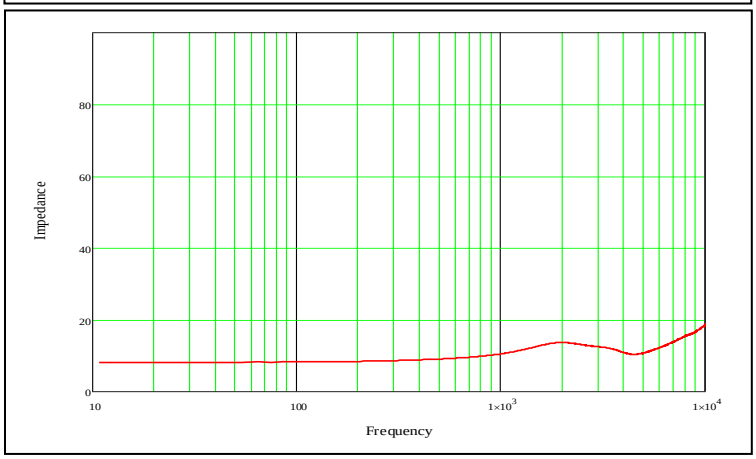




Altec-Lansing UHP-336

Frequency response

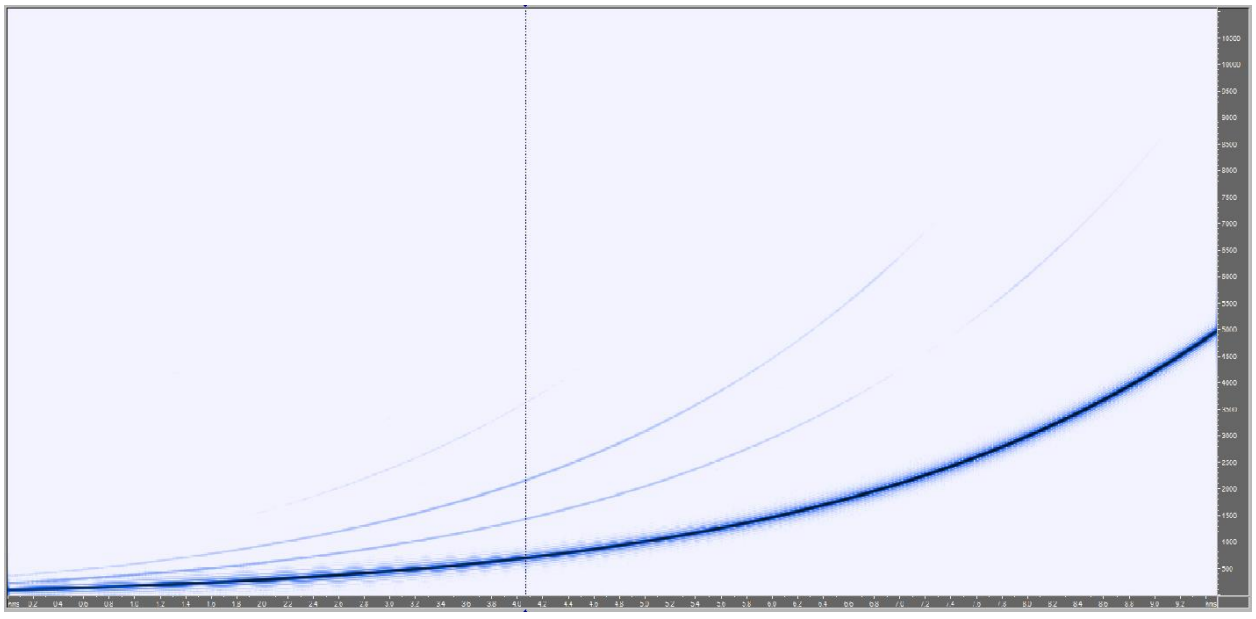




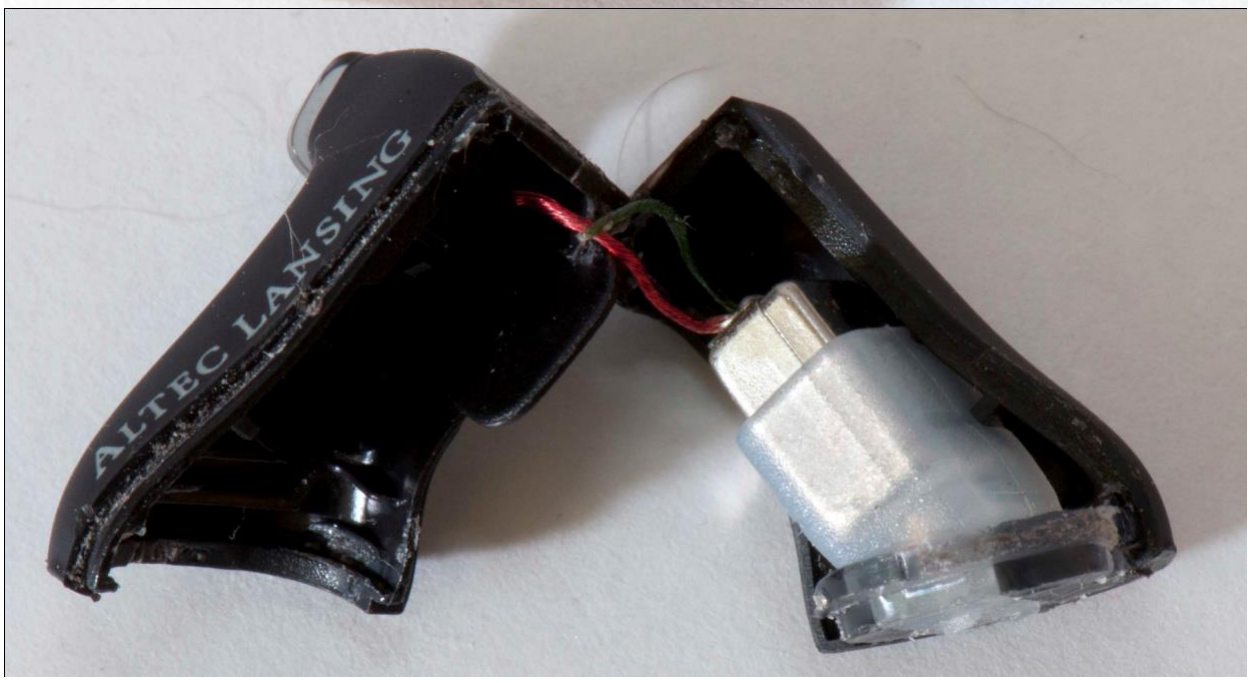
The Altec is an extremely good product. The response is good tilting upward at about 1 dB / oct. and having a very well damped peak at 4 kHz. (perhaps too well damped). The lack of low frequencies seems odd as this device, like all the others, should extend to extremely low frequencies. The falling LF response exceeds that of the HP filter in the mic system.

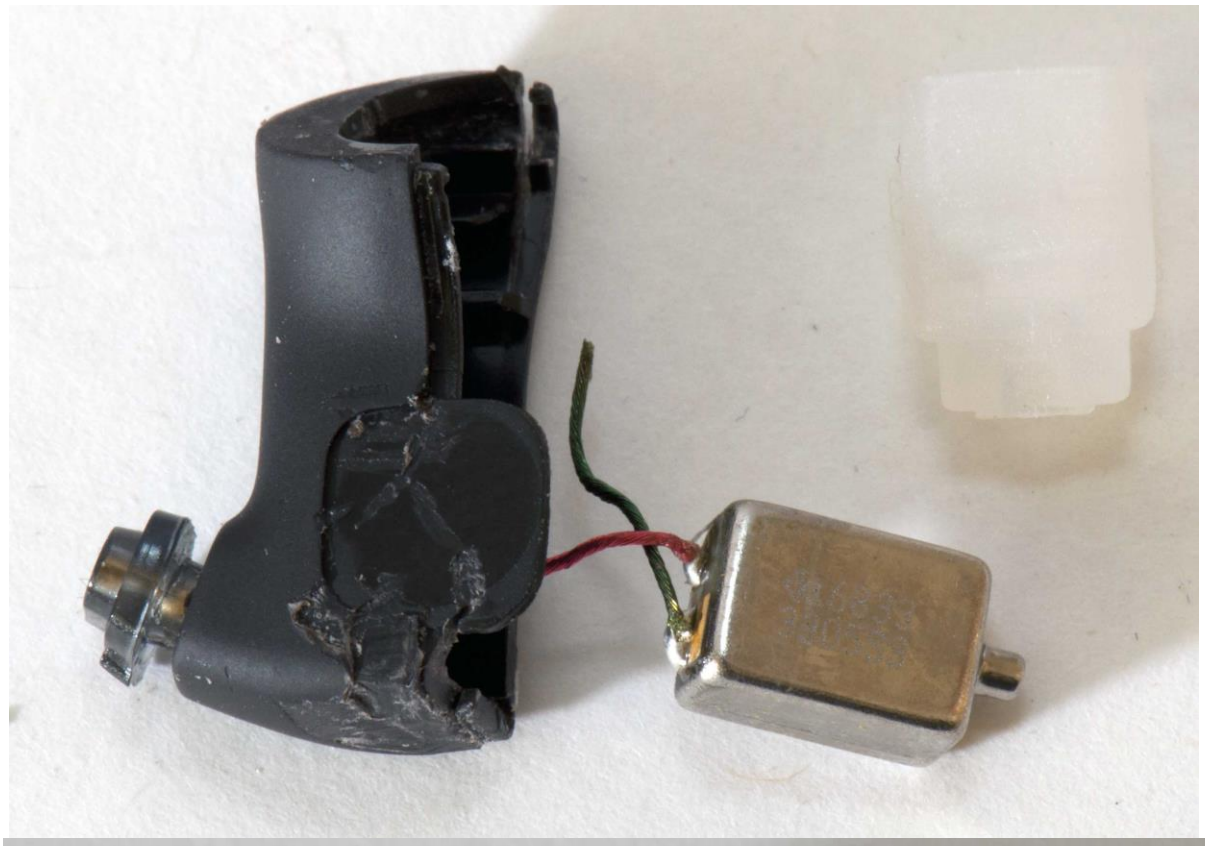
The distortion is about average, some noticable harmonics, but nothing of concern.

This device was my personal favorite as the best "value". It is almost as good as the extremely expensive units, but at a very low cost. This design, labeled as Altec-Lansing, is in fact a rebranding of an Ultimate Ears Super-Fi 5. Its retail price is the same as the Ultimate Ears product, but its street price is far lower. It retails for $130, and yet I bought this pair for $50.




ALTEC LANSING


ALTEC LANSING

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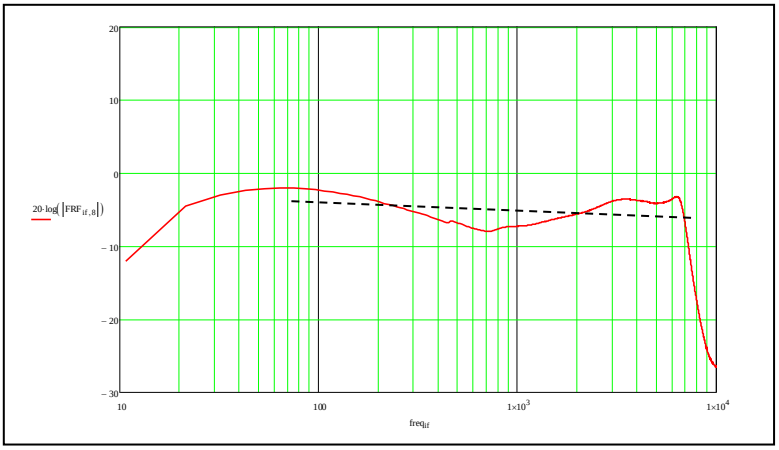
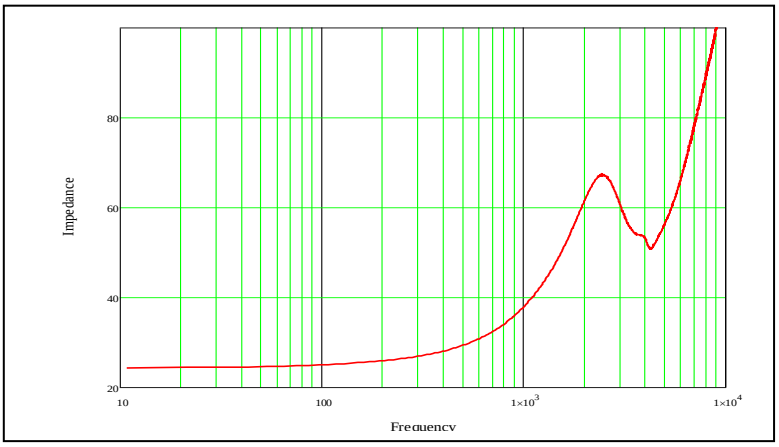
Creative Labs Aurvana In-Ear2

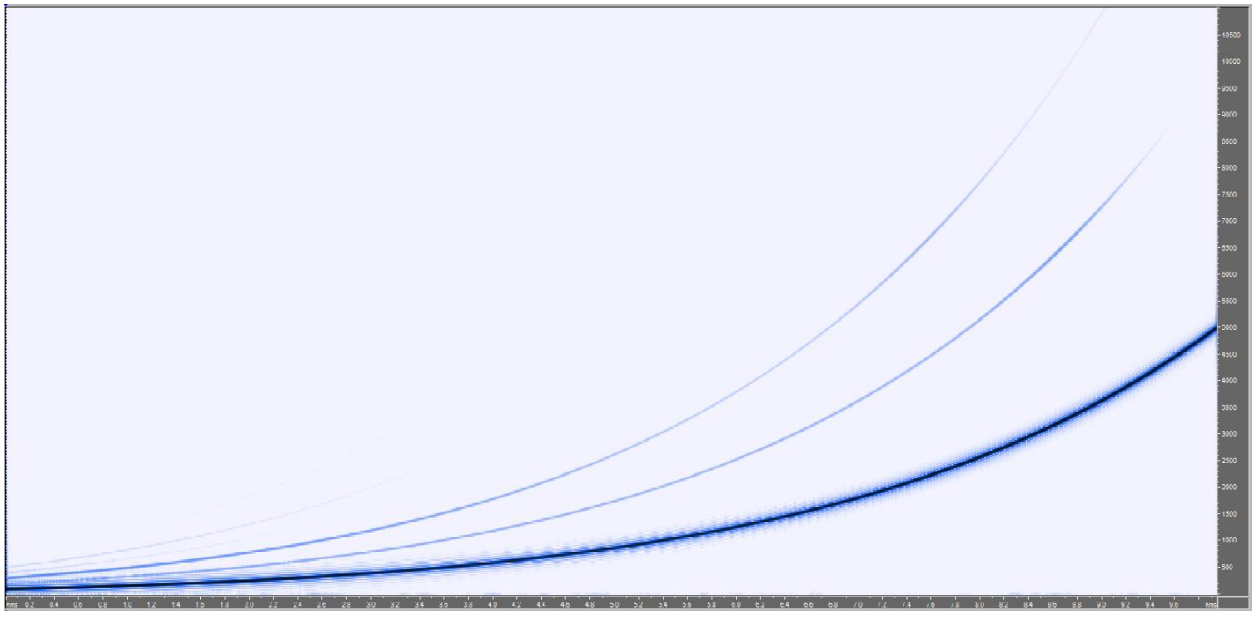
Frequency response

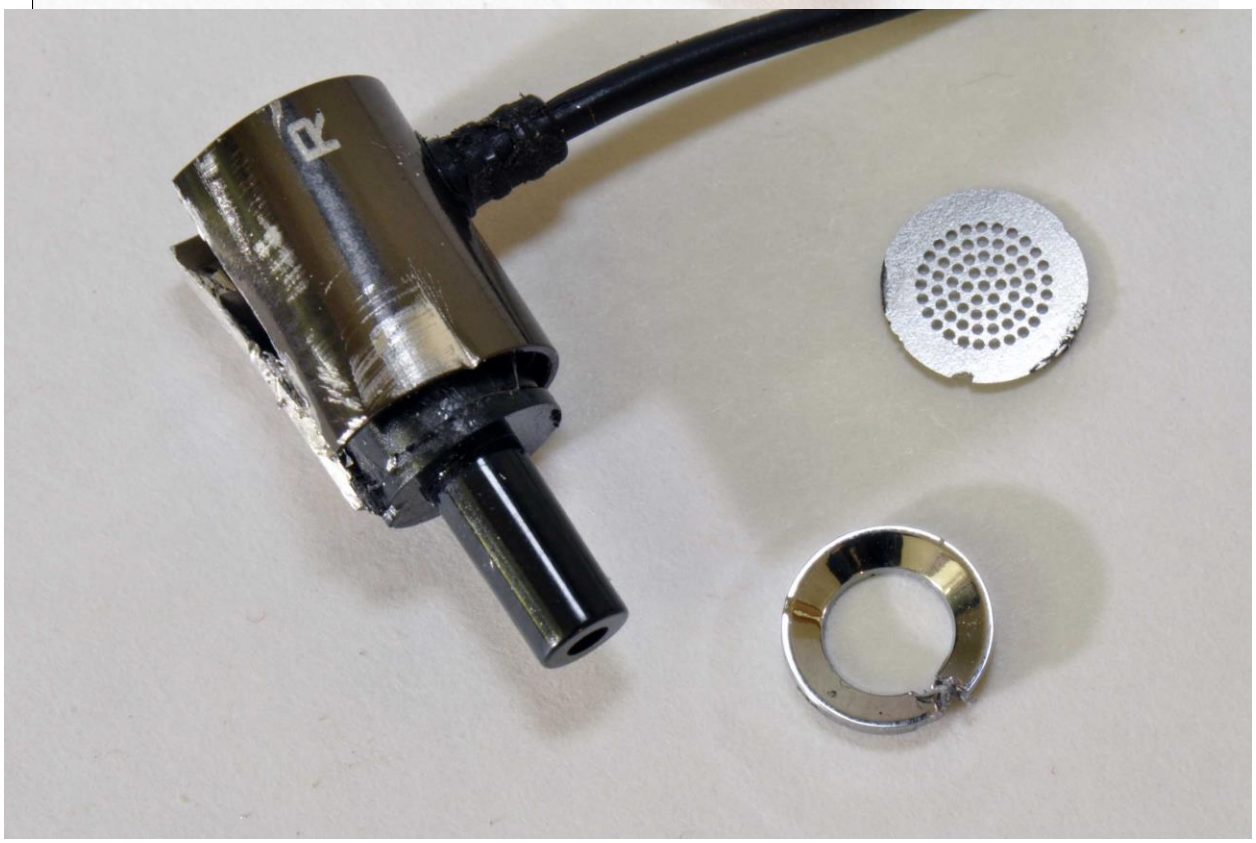


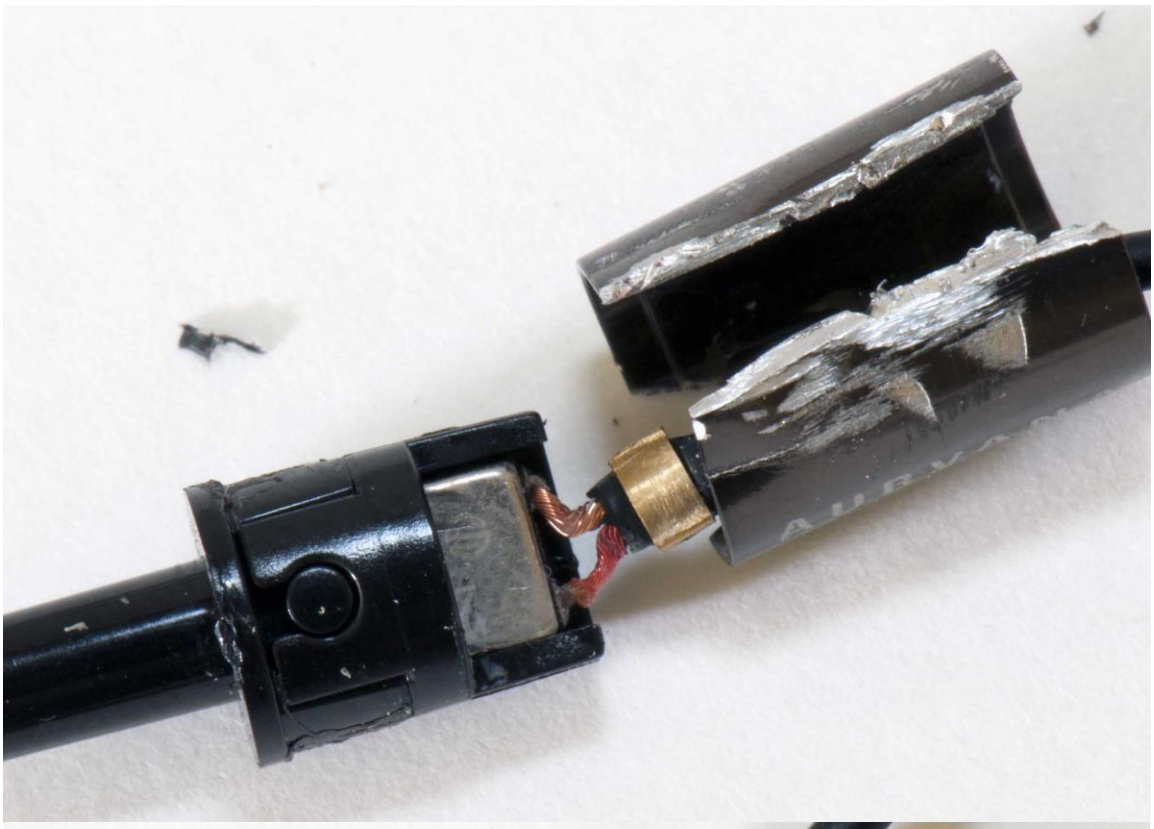


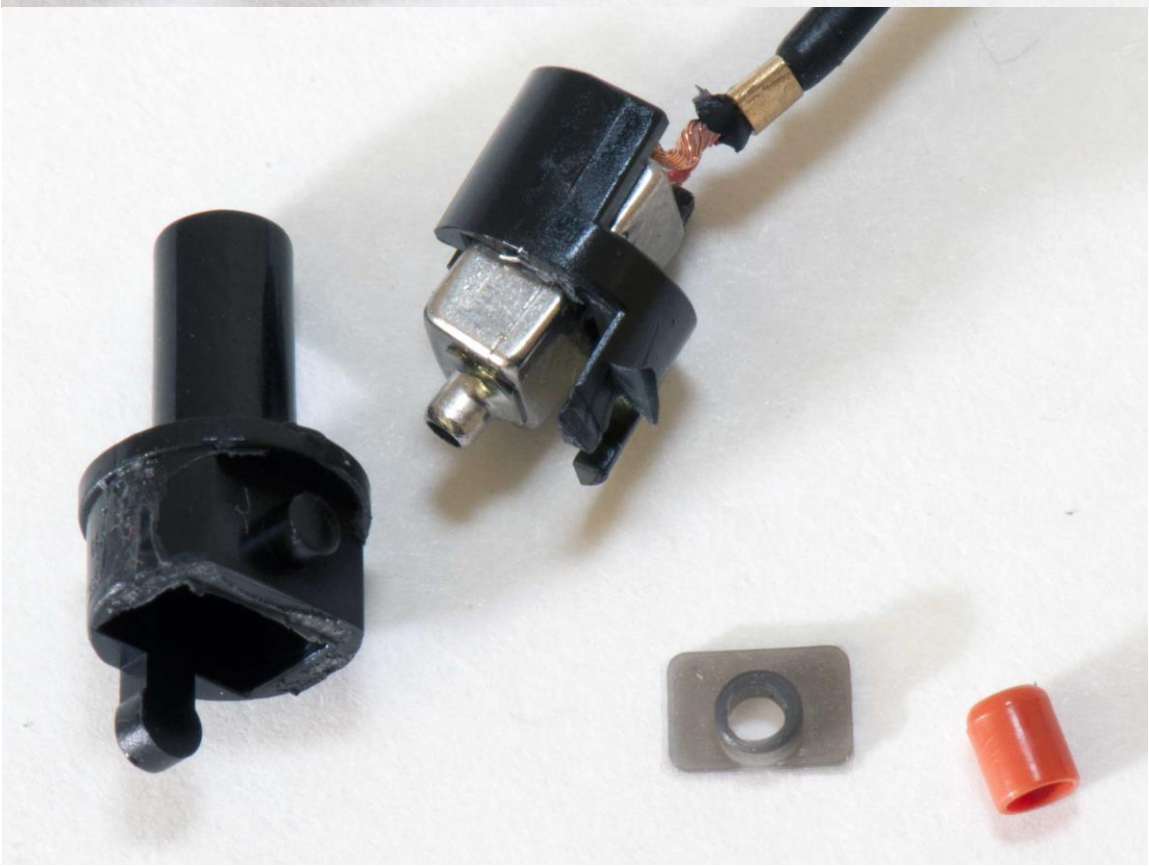
The Creative response actually tilts downward at about 1 dB / oct. It has a very well damped peak at 4 kHz. (perhaps too well damped). It is unclear why the subjective response of this device was so low (unless it was mixed up with the Klipsch). It may be that a falling response is highly undesirable, but outside of this, this these IEMs should have fared well in the subjective rating. It has the desired trough shape and the distortion is not excessive. The impedance rise is extremely high and this may have caused problems with the IPOD amps.

A port damper is readily apparent and the unit appears to snap together. The assembly is quite simple and the appearance is good.




R





Conclusions and Recomendations

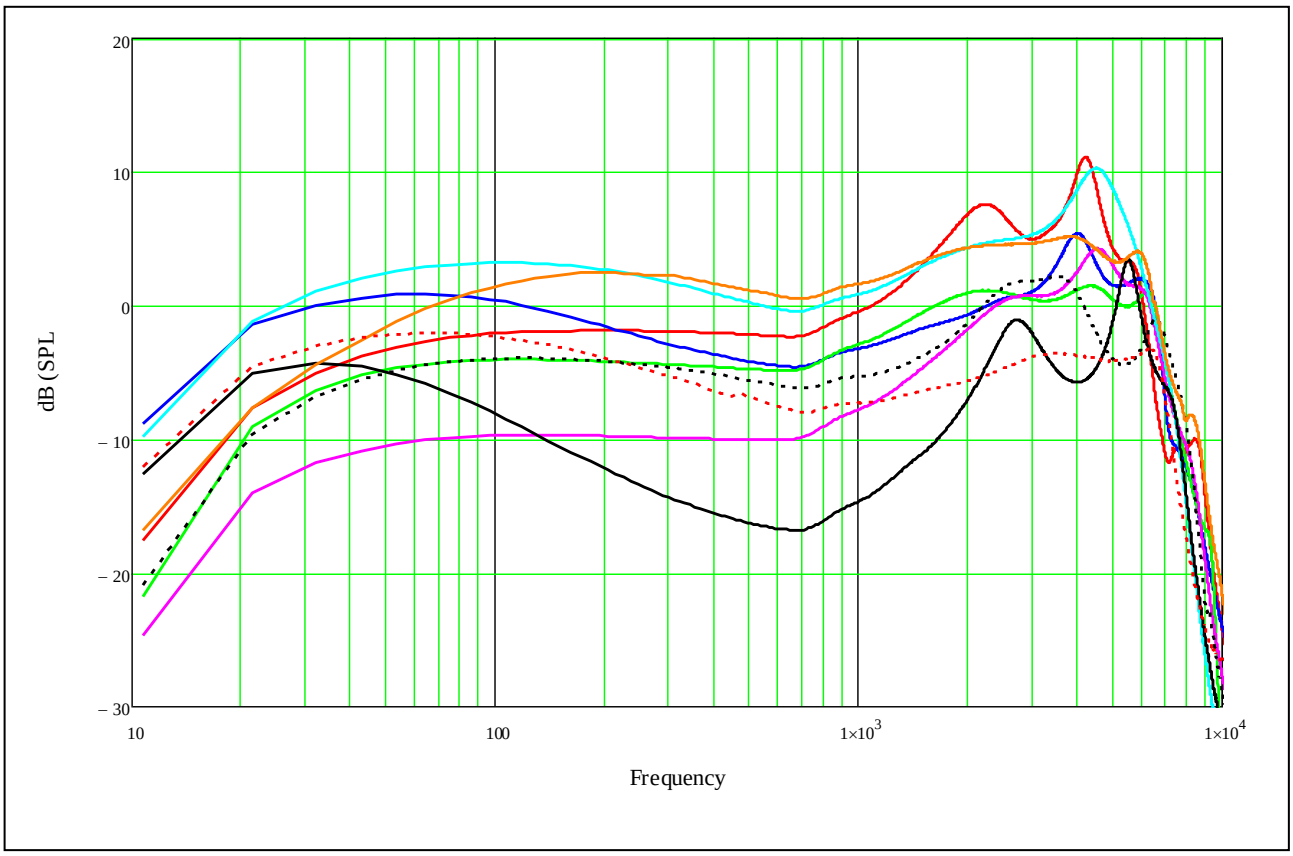
One conclusion from this study is obvious: VRT transducers vastly out perform traditional moving coil designs in IEMs. This is clearly the reason why more and more IEMs are going to VRTs. The only reason that they are not used at 100% of the market is their much higher cost. This higher cost, however comes from the fact that the VRT had been used exclusively in hearing aids where the cost is not a significant factor. Should the price of VRTs approach the price of the moving coil designs, the marketplace would certianly go to VRTs at 100% installation rate (I would estimate that its now at only about 15%). This exposes a massive market potential for these designs and an extremely limited supply base (only Knowles and Sinion to my knowledge) and competition.

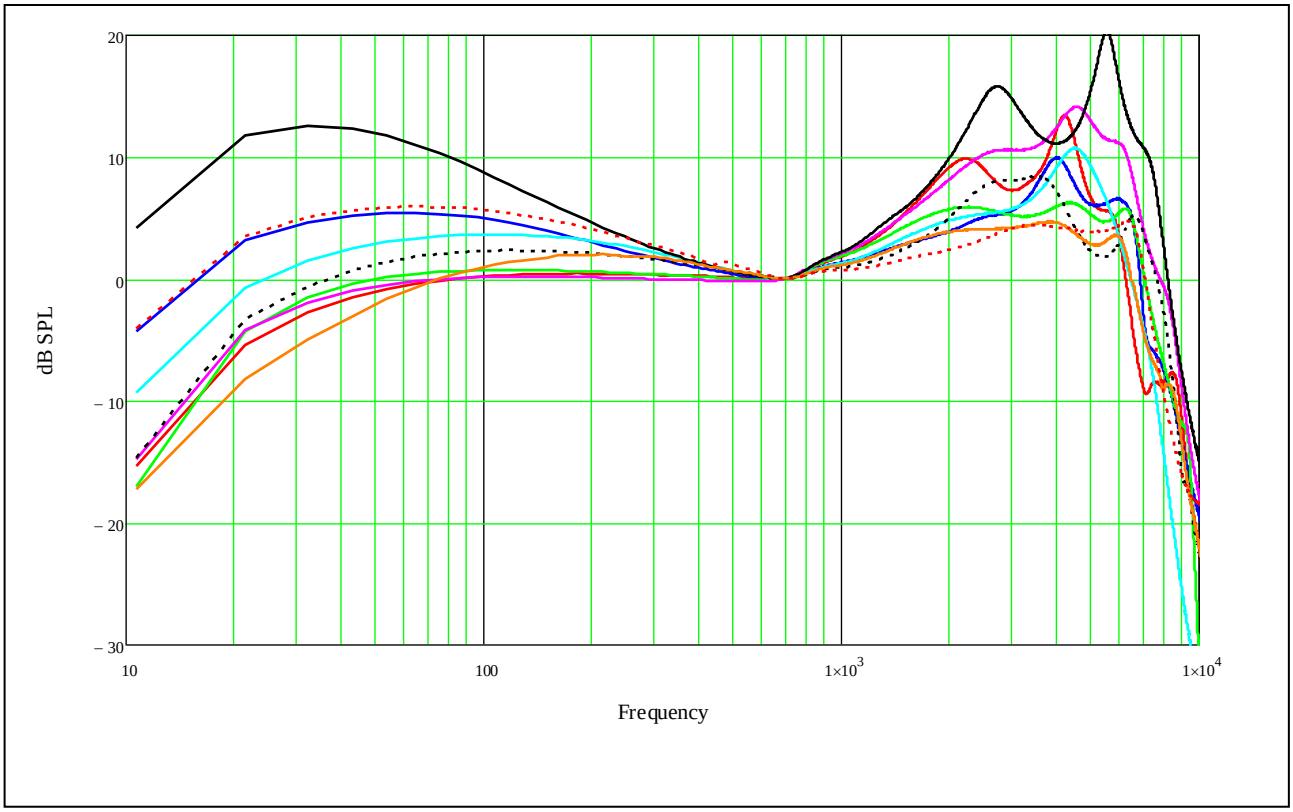
IEM VRTs are very different than hearing aid VRTs: they are, in general, much larger and have much lower impedances than than hearing aid VRTs. This means that NJL should be looking at making a larger device with a lower impedance than the prototype that we are currently making.

It appears to me that the market potential for IEM VRTs is massive, there is no question that it will far exceed the market for hearing aid VRTs. An ideal product for NJL to enter the marketplace with would be a two transducer device at the same price point as the current single transducer designs. A product like this would seriously shake up the industry as it would demonstrate where the price points need to be and would put serious pressure on Knowles and Sinion to lower there prices. This situation would make NJL the company in the comanding position of being able to dictate the price point. Instead of being the company having to match others prices, its the other company that has to match NJL price.

Appendix

The folowing plots show all nine devices plotted on a single graph. In one case the curves are un-normalized in the other plot they are all normalized at 700 Hz. The range of responses can be seen in the second and the range of sensitivities can be seen in the first.


20
10
0
– 10
– 20
– 30
dB (SPL
10
100
1×10^3
1×10^4
Frequency


20
10
0
– 10
– 20
– 30
dB SPL
10
100
1×10^3
1×10^4
Frequency