**Considerations on single ended operation of the F5X (P)**

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The voltage transfer matrix $H$ represents the amplifier voltage transfer function from the input to the output terminals.

$$V_o = HV_i$$

The output voltage vector represents the voltages measured at both output terminals 1 and 2 (often labelled with + and - instead of 1 and 2)

$$V_o = \begin{pmatrix} V_{o_1} \\ V_{o_2} \end{pmatrix}$$

The input voltage vector represents the voltage signals applied to both input terminals 1 and 2

$$V_i = \begin{pmatrix} V_{i_1} \\ V_{i_2} \end{pmatrix}$$

The voltage transfer matrix from input to output is defined as

$$H = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix}$$

Making the matrix equation explicit gives

$$\begin{pmatrix} V_{o_1} \\ V_{o_2} \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \begin{pmatrix} V_{i_1} \\ V_{i_2} \end{pmatrix}$$

Lets assume we have a second amplfier with the transfer matrix

$$G = \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix}$$

and we put this in series with the first amplifer we get the following transfer matrix

$$GH = \begin{pmatrix} g_{11}h_{11} + g_{12}h_{21} & g_{11}h_{12} + g_{12}h_{22} \\ g_{21}h_{11} + g_{22}h_{21} & g_{21}h_{12} + g_{22}h_{22} \end{pmatrix}$$

which simplifies in the case both amplifier stages are itentical

$$M = H^2 = \begin{pmatrix} h_{11}^2 + h_{12}h_{21} & h_{11}h_{12} + h_{12}h_{22} \\ h_{11}h_{21} + h_{21}h_{22} & h_{22}^2 + h_{12}h_{21} \end{pmatrix}$$

If we are interested in the differential and common mode response at the outputs we just need to transform the output signals accordingly

$$\begin{pmatrix} V_{o_{diff}} \\ V_{o_{comm}} \end{pmatrix} = \begin{pmatrix} 1 & -1 \\ \frac{1}{2} & \frac{1}{2} \end{pmatrix} \begin{pmatrix} V_{o_1} \\ V_{o_2} \end{pmatrix}$$

$$V = \begin{pmatrix} 1 & -1 \\ \frac{1}{2} & \frac{1}{2} \end{pmatrix}$$

The determinant equals: $1$

The eigenvectors are :
$$\left\{ \begin{pmatrix} \frac{1}{2} - \frac{1}{2} i\sqrt{7} \\ 1 \end{pmatrix} \right\} \leftrightarrow \frac{3}{4} - \frac{1}{4} i\sqrt{7}, \left\{ \begin{pmatrix} \frac{1}{2} i\sqrt{7} + \frac{1}{2} \\ 1 \end{pmatrix} \right\} \leftrightarrow \frac{1}{4} i\sqrt{7} + \frac{3}{4},$$

and the absolute values of the eigenvalues are

$$\left| \frac{3}{4} - \frac{1}{4} i\sqrt{7} \right| = 1.0$$
$$\left| \frac{1}{4} i\sqrt{7} + \frac{3}{4} \right| = 1.0$$

The determinant and the eigenvalues equal one. No voltage gain or loss here as it should be.
In the same way the input signals at both terminals could be represented as common and differential voltage inputs

$$\begin{pmatrix} V_{i_1} \\ V_{i_2} \end{pmatrix} = \begin{pmatrix} \frac{1}{2} & 1 \\ -\frac{1}{2} & 1 \end{pmatrix} \begin{pmatrix} V_{i_{diff}} \\ V_{i_{comm}} \end{pmatrix}$$

with

$$V^{-1} = \begin{pmatrix} \frac{1}{2} & 1 \\ -\frac{1}{2} & 1 \end{pmatrix}$$

Now everthing is in place to compute the differential and common mode output voltage response to the differential and common input voltage signals from the measured transfer matrix elements

$$\begin{pmatrix} V_{o_{diff}} \\ V_{o_{comm}} \end{pmatrix} = H^{'} \begin{pmatrix} V_{i_{diff}} \\ V_{i_{comm}} \end{pmatrix}$$

$$H^{'} = VHV^{-1} = \begin{pmatrix} \frac{1}{2}h_{11} - \frac{1}{2}h_{12} - \frac{1}{2}h_{21} + \frac{1}{2}h_{22} & h_{11} + h_{12} - h_{21} - h_{22} \\ \frac{1}{4}h_{11} - \frac{1}{4}h_{12} + \frac{1}{4}h_{21} - \frac{1}{4}h_{22} & \frac{1}{2}h_{11} + \frac{1}{2}h_{12} + \frac{1}{2}h_{21} + \frac{1}{2}h_{22} \end{pmatrix}$$

Evaluating the matrices with the maesured passband matrix elements

$$h_{11} = 10^{11/20}$$
$$h_{22} = 10^{11/20}$$
$$h_{21} = -10^{7.5/20}$$
$$h_{12} = -10^{7.5/20}$$

we get

$$H = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} = \begin{pmatrix} 3.5481 & -2.3714 \\ -2.3714 & 3.5481 \end{pmatrix}$$

and

$$H^{'} = \begin{pmatrix} \frac{1}{2}h_{11} - \frac{1}{2}h_{12} - \frac{1}{2}h_{21} + \frac{1}{2}h_{22} & h_{11} + h_{12} - h_{21} - h_{22} \\ \frac{1}{4}h_{11} - \frac{1}{4}h_{12} + \frac{1}{4}h_{21} - \frac{1}{4}h_{22} & \frac{1}{2}h_{11} + \frac{1}{2}h_{12} + \frac{1}{2}h_{21} + \frac{1}{2}h_{22} \end{pmatrix} = \begin{pmatrix} 5.9195 & 0 \\ 0 & 1.1768 \end{pmatrix}$$

As a result we will get the voltage transfer equations in both representations

$$\begin{pmatrix} V_{o_1} \\ V_{o_2} \end{pmatrix} = \begin{pmatrix} 3.5481 & -2.3714 \\ -2.3714 & 3.5481 \end{pmatrix} \begin{pmatrix} V_{i_1} \\ V_{i_2} \end{pmatrix}$$

$$\begin{pmatrix} V_{o_{diff}} \\ V_{o_{comm}} \end{pmatrix} = \begin{pmatrix} 5.9195 & 0 \\ 0 & 1.1768 \end{pmatrix} \begin{pmatrix} V_{i_{diff}} \\ V_{i_{comm}} \end{pmatrix}$$

Inspecting the transfer matrix above we could conclude that we have a differential amplifier with a gain factor of 5.9 ($20\log_{10}(5.9) = 15.4dB$) and a common mode follower (gain almost 1)

Next we can look into what happens to differential / common mode outputs if we we drive it single ended

$$\begin{pmatrix} V_{o_1} \\ V_{o_2} \end{pmatrix} = \begin{pmatrix} 3.5481 & -2.3714 \\ -2.3714 & 3.5481 \end{pmatrix} \begin{pmatrix} V_{SE} \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} V_{o_1} \\ V_{o_2} \end{pmatrix} = \begin{pmatrix} 3.5481 \\ -2.3714 \end{pmatrix} V_{SE}$$

So single ended operation leads to different amplitudes at the outputs. The ratio of the output amplitudes equals 3.5dB or a factor of about 1.5

Looking at the outputs from common mode/differential mode perspective we are getting

$$\begin{pmatrix} V_{o_{diff}} \\ V_{o_{comm}} \end{pmatrix} = VH \begin{pmatrix} V_{SE} \\ 0 \end{pmatrix}$$

$$VH = \begin{pmatrix} 5.9195 & -5.9195 \\ 0.58838 & 0.58838 \end{pmatrix}$$

$$\begin{pmatrix} V_{o_{diff}} \\ V_{o_{comm}} \end{pmatrix} = \begin{pmatrix} 5.9195 \\ 0.58838 \end{pmatrix} V_{SE}$$

which means we are getting besides the differential gain also a common mode gain, both as anticipated.

So the difference in signal amplitues at the output terminals could also be looked on as a result of an added common mode swing to the differential output signal.

So we will not get a perfect SE to balanced conversion using a balanced (pre) amp.

But it should improve if we would put two of them in series, for instance an F5XP and an F5X.

If we assume both amplifers will have the same obove transfer matrix then we will get the following total transfer matrix

$$H^2 = \begin{pmatrix} h_{11}^2 + h_{12}h_{21} & h_{11}h_{12} + h_{12}h_{22} \\ h_{11}h_{21} + h_{21}h_{22} & h_{22}^2 + h_{12}h_{21} \end{pmatrix} = \begin{pmatrix} 18.213 & -16.828 \\ -16.828 & 18.213 \end{pmatrix}$$

The ratio of output signal amplitudes is $18.213/16.828 = 1.0823$ or $20\log_{10}(1.0823) = 0.7$ dB now. This could be regarded as quite well balanced already.
If we look at the common/differential output representation we get

$$VH^2 = \begin{pmatrix} 35.041 & -35.041 \\ 0.69238 & 0.69238 \end{pmatrix}$$

$$\begin{pmatrix} V_{o_{diff}} \\ V_{o_{comm}} \end{pmatrix} = \begin{pmatrix} 35.041 \\ 0.69238 \end{pmatrix} V_{SE}$$

Just for curiosity we could continue like this. If we assume a third amplifer in series then the amplitude level will drop to a 1% level

$$H^3 = \begin{pmatrix} 104.53 & -102.90 \\ -102.90 & 104.53 \end{pmatrix}$$

and so forth

$$H^4 = \begin{pmatrix} 614.88 & -612.96 \\ -612.96 & 614.88 \end{pmatrix}$$

**Conclusion**: Although a balanced amp like the F5XP will (very likely, I only have measurements from the F5X) not create a perfectly balanced output from a single ended input, a combination of a F5XP preamp and a F5X power amp will result into a already quite well balanced (about 8% difference in amplitude) output signal at the speaker terminals.

**Hint**: With the simple math shown above one could easily derive balanced amplifier voltage transfers from single ended measurements. There are no SE to balanced or backward converters needed for measurements of the dynamic response of a balanced amplifier. This makes the measurements much more simple and transparent and hence, less error-prone.