Related to a blog post on www.gcamp6f.com by Peter Rupprecht: p.t.r.rupprecht+blog@gmail.com

h = focal length of tunable lens (ETL)
g = focal length of relay lens 3
f = focal length of relay lens 4
e = focal length of relay lens 1
d = focal length of relay lens 2
c = focal length of scan lens
b = focal length of tube lens
a = focal length of objective
z = focal shift

q0 and q1 are the complex beam parameters before and after going through all these optical elements (compare https://en.wikipedia.org/wiki/Complex_beam_parameter for details).

The goal of this calculation is to find the real part of the complex beam parameter after going through the entire system. The zero node of this real part is the value where the beam waist is minimal, i.e., where the focus of the beam is. This allows us to compute the focus shift (z) as a function of the focal length of the ETL (h). Check out the blog post for details and visualizations.

```
In[8]:= M = Simplify[{{1, a + z}, {0, 1}}.
    {{1, 0}, {-1/a, 1}}.{{1, a + b}, {0, 1}}.{{1, 0}, {-1/b, 1}}.
  {{1, b + c}, {0, 1}}.{{1, 0}, {-1/c, 1}}.
    {{1, c + d}, {0, 1}}.{{1, 0}, {-1/d, 1}}.
  {{1, d + e}, {0, 1}}.{{1, 0}, {-1/e, 1}}.
    {{1, e + f}, {0, 1}}.{{1, 0}, {-1/f, 1}}.
  {{1, f + g}, {0, 1}}.{{1, 0}, {-1/g, 1}}.{{1, g}, {0, 1}}.{{1, 0}, {-1/h, 1}}]
```

Out[8]= $\left\{\left\{\frac{a\,c\,e\,g}{b\,d\,f\,h}+\frac{b\,d\,f\,z}{a\,c\,e\,g},\ -\frac{a\,c\,e\,g}{b\,d\,f}\right\},\left\{\frac{b\,d\,f}{a\,c\,e\,g},\ 0\right\}\right\}$

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In[9]:= q0 = I * zR0
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Out[9]= $i\,zR0$

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In[10]:= q1 = (M[[2, 1]] + M[[2, 2]] / q0) / (M[[1, 1]] + M[[1, 2]] / q0)
```

Out[10]= $\frac{b\,d\,f}{a\,c\,e\,g\left(\frac{a\,c\,e\,g}{b\,d\,f\,h}+\frac{b\,d\,f\,z}{a\,c\,e\,g}+\frac{i\,a\,c\,e\,g}{b\,d\,f\,zR0}\right)}$

In[11]:= **RR = ComplexExpand[q1]**

Out[11]=

$$\frac{1}{h\left(\left(\frac{a\,c\,e\,g}{b\,d\,f\,h}+\frac{b\,d\,f\,z}{a\,c\,e\,g}\right)^2+\frac{a^2\,c^2\,e^2\,g^2}{b^2\,d^2\,f^2\,zR0^2}\right)}+\frac{b^2\,d^2\,f^2\,z}{a^2\,c^2\,e^2\,g^2\left(\left(\frac{a\,c\,e\,g}{b\,d\,f\,h}+\frac{b\,d\,f\,z}{a\,c\,e\,g}\right)^2+\frac{a^2\,c^2\,e^2\,g^2}{b^2\,d^2\,f^2\,zR0^2}\right)}-\frac{i}{\left(\left(\frac{a\,c\,e\,g}{b\,d\,f\,h}+\frac{b\,d\,f\,z}{a\,c\,e\,g}\right)^2+\frac{a^2\,c^2\,e^2\,g^2}{b^2\,d^2\,f^2\,zR0^2}\right)zR0}$$

In[12]:= **Simplify**

$$\mathrm{Simplify}\left[\frac{1}{h\left(\left(\frac{a\,c\,e\,g}{b\,d\,f\,h}+\frac{b\,d\,f\,z}{a\,c\,e\,g}\right)^2+\frac{a^2\,c^2\,e^2\,g^2}{b^2\,d^2\,f^2\,zR0^2}\right)}+\frac{b^2\,d^2\,f^2\,z}{a^2\,c^2\,e^2\,g^2\left(\left(\frac{a\,c\,e\,g}{b\,d\,f\,h}+\frac{b\,d\,f\,z}{a\,c\,e\,g}\right)^2+\frac{a^2\,c^2\,e^2\,g^2}{b^2\,d^2\,f^2\,zR0^2}\right)}\right]$$

Out[12]=

$$\frac{b^2\,d^2\,f^2\,h\left(a^2\,c^2\,e^2\,g^2+b^2\,d^2\,f^2\,h\,z\right)zR0^2}{2\,a^2\,b^2\,c^2\,d^2\,e^2\,f^2\,g^2\,h\,z\,zR0^2+b^4\,d^4\,f^4\,h^2\,z^2\,zR0^2+a^4\,c^4\,e^4\,g^4\left(h^2+zR0^2\right)}$$