EXAMPLE

17. THE INPUT FILTER PROBLEM OF A SWITCHED-MODE REGULATOR

A different application of the EET is useful in design of the input filter for a switching regulator.

"The Input Filter Problem" was discussed in a 1976 paper:

R.D.Middlebrook, "Input Filter Considerations in Design and Application of Switching Regulators," IEEE Industry Applications Society Annual Meeting, 1976 Record, pp. 366 - 382.

Problem:

How to design an input filter for a switched-mode regulator without significantly disturbing its properties.

Conclusion:

The output impedance Z_s of the input filter should be much less than certain line input impedances of the regulator.

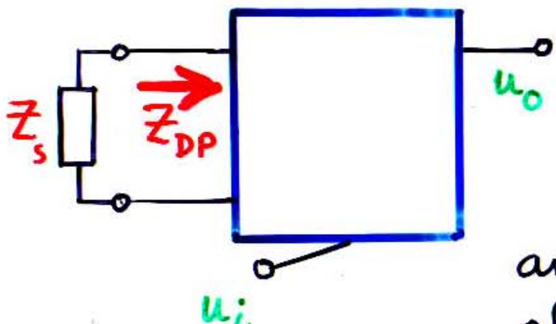
The design-oriented inequalities can easily be established by use of the Extra Element Theorem.

Objective

To find conditions on the input filter so that properties of the regulator are unaffected.

Approach

Use the Extra Element Theorem (EET)



$$\frac{u_o}{u_i} = \left.\frac{u_o}{u_i}\right|_{Z_s=0} \cdot \frac{1 + \frac{Z_s}{Z_n}}{1 + \frac{Z_s}{Z_d}}$$

$\frac{u_o}{u_i}$: any transfer function of a linear system, e.g. gain, loop gain, output impedance

$\left.\frac{u_o}{u_i}\right|_{Z_s=0}$: same tranfer function with $Z_s = 0$.

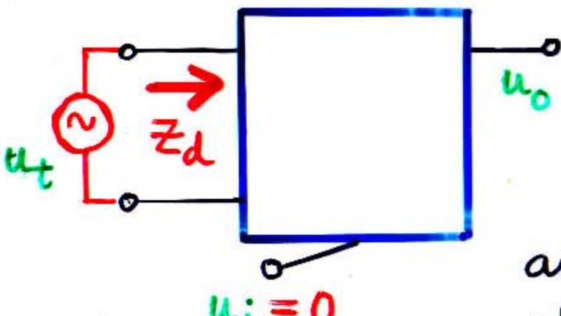
Z_n, Z_d are dpi's (driving point impedances) seen by a test signal u_t applied in place of Z_s:

Objective

To find conditions on the input filter so that properties of the regulator are unaffected.

Approach

Use the Extra Element Theorem (EET)



$$\frac{u_o}{u_i} = \left.\frac{u_o}{u_i}\right|_{Z_s=0} \cdot \frac{1 + \frac{Z_s}{Z_n}}{1 + \frac{Z_s}{Z_d}}$$

any transfer function of a linear system, e.g. gain, loop gain, output impedance

same tranfer function with $Z_s = 0$.

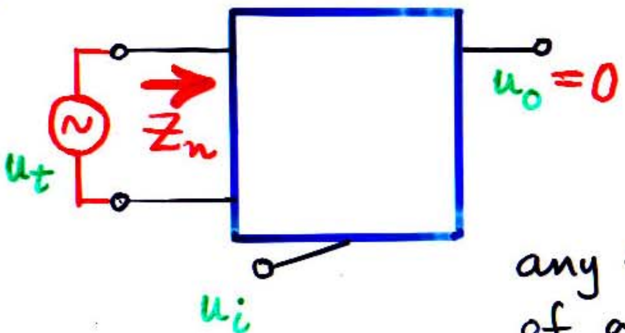
$Z_d = Z_{DP}$ seen by u_t with $u_i = 0$ (single injection)

Objective

To find conditions on the input filter so that properties of the regulator are unaffected.

Approach

Use the Extra Element Theorem (EET)



$$\frac{u_o}{u_i} = \left.\frac{u_o}{u_i}\right|_{Z_s=0} \cdot \frac{1 + \frac{Z_s}{Z_n}}{1 + \frac{Z_s}{Z_d}}$$

any transfer function of a linear system, e.g. gain, loop gain, output impedance

same tranfer function with $Z_s = 0$.

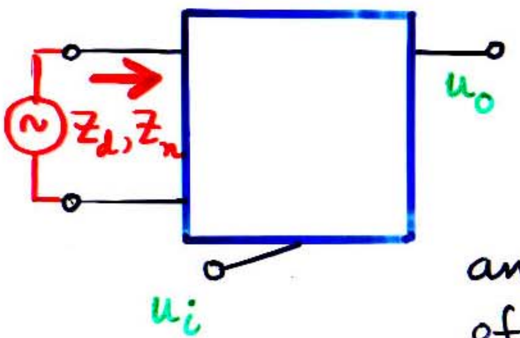
$Z_n = Z_{DP}$ seen by u_t in presence of u_i adjusted to make $u_o = 0$
(null double injection)

Objective

To find conditions on the input filter so that properties of the regulator are unaffected.

Approach

Use the Extra Element Theorem (EET)



$$\frac{u_o}{u_i} = \left.\frac{u_o}{u_i}\right|_{Z_s=0} \cdot \frac{1+\frac{Z_s}{Z_n}}{1+\frac{Z_s}{Z_d}}$$

$\frac{u_o}{u_i}$: any transfer function of a linear system, e.g. gain, loop gain, output impedance

$\left.\frac{u_o}{u_i}\right|_{Z_s=0}$: same tranfer function with $Z_s = 0$.

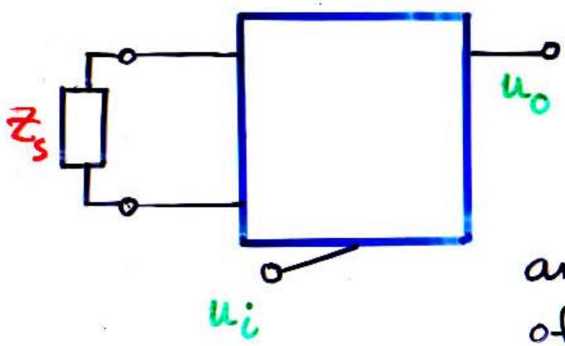
Note that, even for a given element Z_s, Z_n but not Z_d are different for different transfer functions of the same system (different u_i's and u_o's).

Objective

To find conditions on the input filter so that properties of the regulator are unaffected.

Approach

Use the Extra Element Theorem (EET)



$$\frac{u_o}{u_i} = \left.\frac{u_o}{u_i}\right|_{Z_s=0} \cdot \frac{1 + \frac{Z_s}{Z_n}}{1 + \frac{Z_s}{Z_d}}$$

$\frac{u_o}{u_i}$: any transfer function of a linear system, e.g. gain, loop gain, output impedance

$\left.\frac{u_o}{u_i}\right|_{Z_s=0}$: same tranfer function with $Z_s = 0$.

Application of the EET to a regulator with input filter:

Identify Z_s as the output impedance of the input filter

Hence, the design criteria are:

$Z_s \ll Z_d, Z_n$ corresponding to each property (transfer function) of interest.

The EET for one extra element Z_s is

$$\frac{u_o}{u_i} = \left.\frac{u_o}{u_i}\right|_{Z_s=0} \frac{1+\frac{Z_s}{Z_n}}{1+\frac{Z_s}{Z_d}}$$

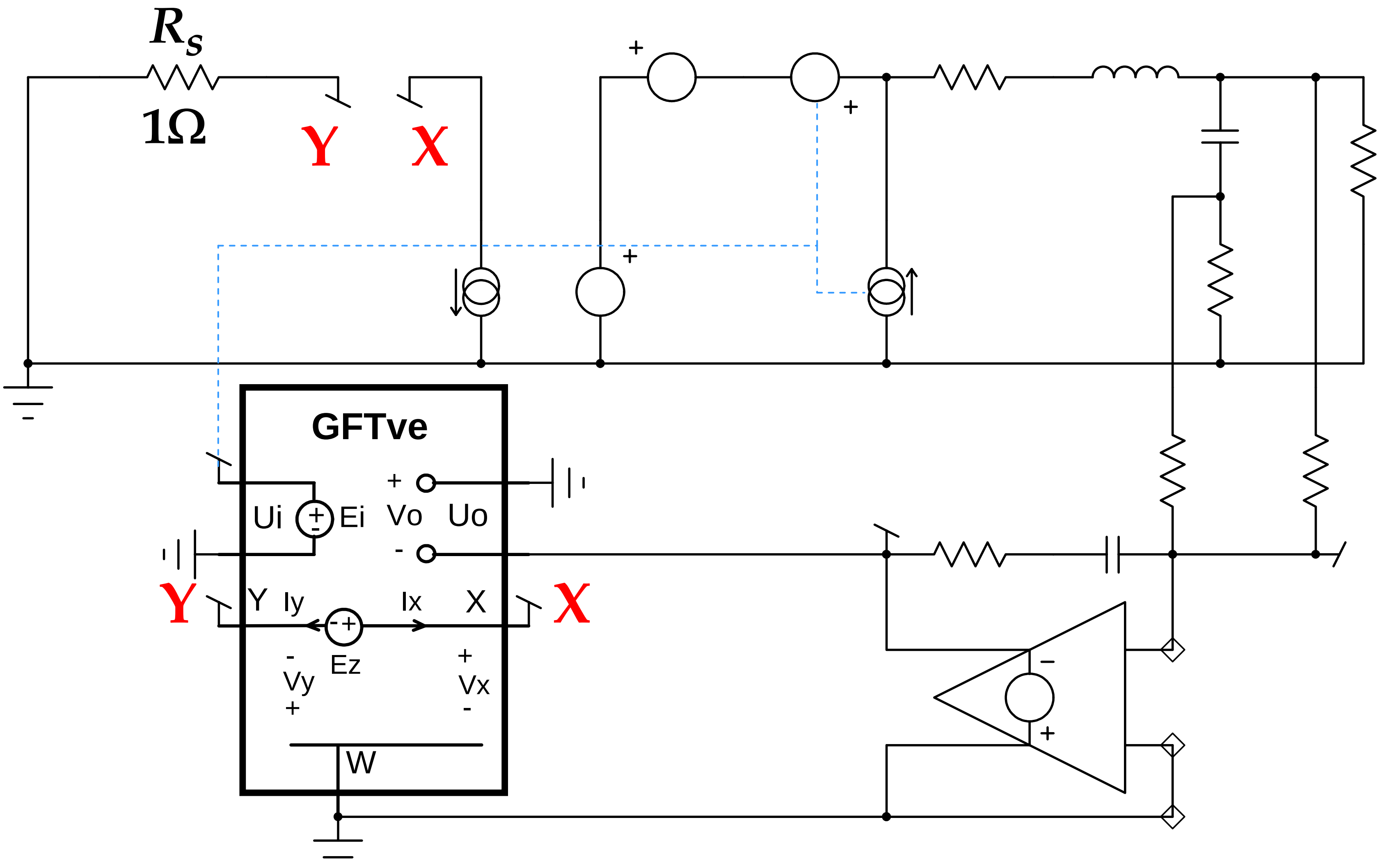
This is the same as the GFT for one injected test signal:

$$H = H_\infty \frac{1+\frac{1}{T_n}}{1+\frac{1}{T}} = H_\infty D D_n$$

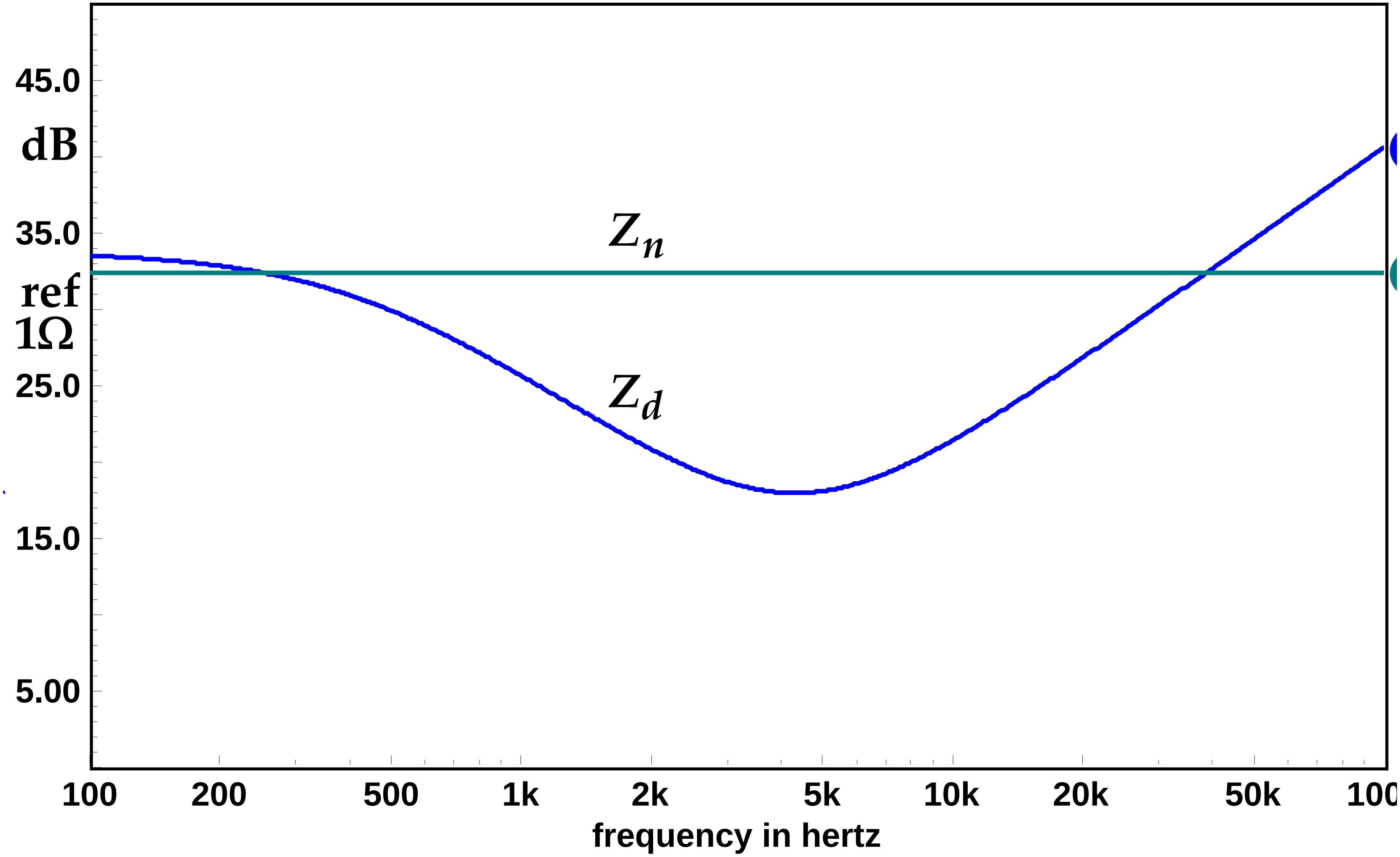
where $H =$ loopgain[with Z_s] and $H_\infty =$ loopgain[$Z_s = 0$].

Z_d and Z_n can be found from T and T_n by test voltage e_z injection at a source resistance $Z_s = R_s = 1\Omega$. Then,

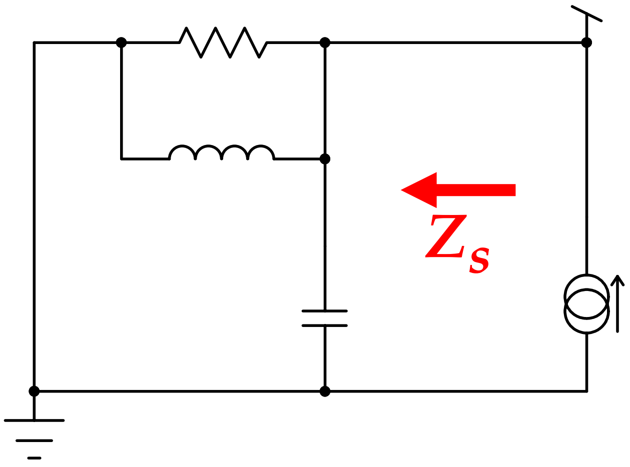
$Z_d = T$ and $Z_n = T_n$



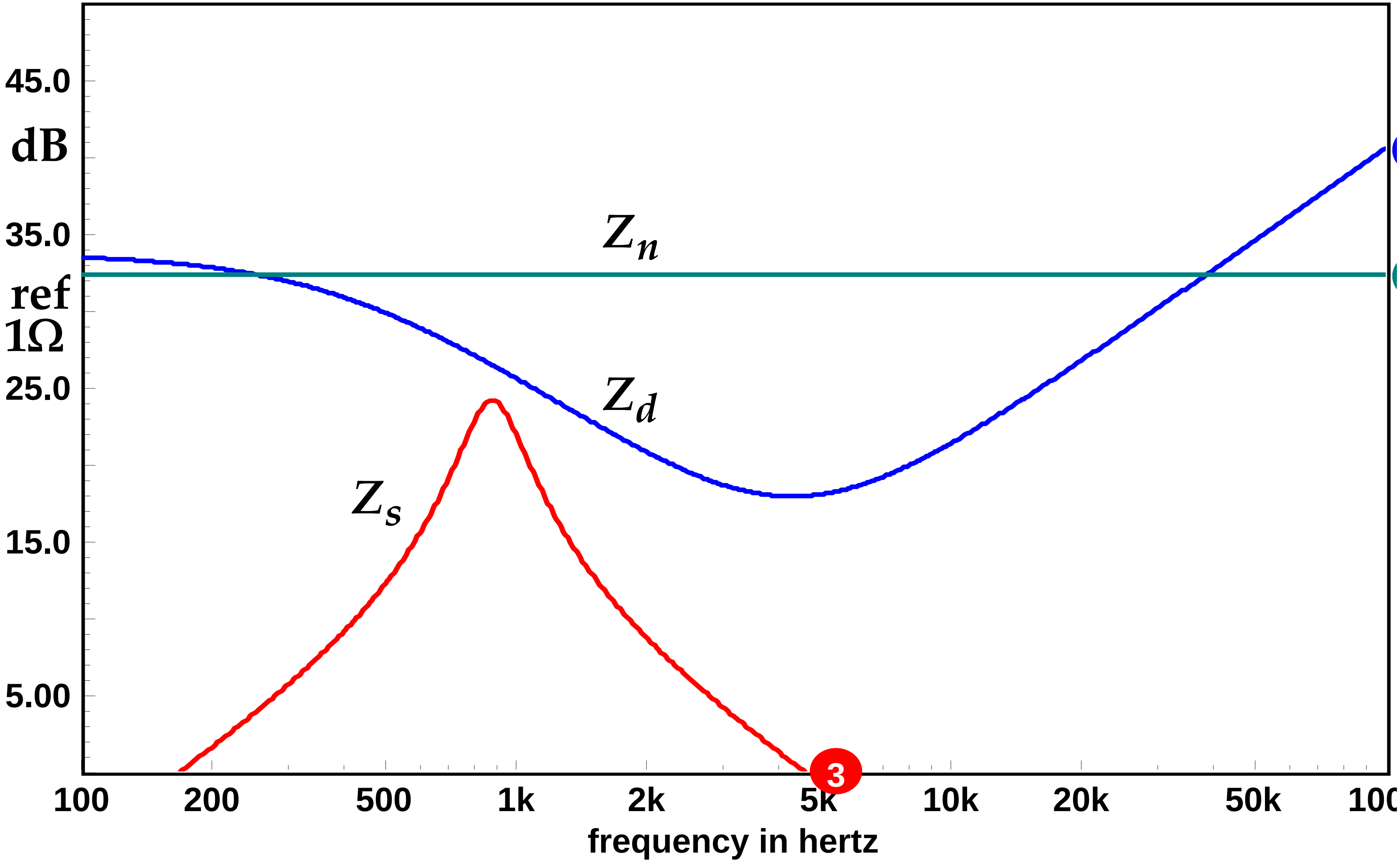
Values as in 1976 Paper Fig. 13

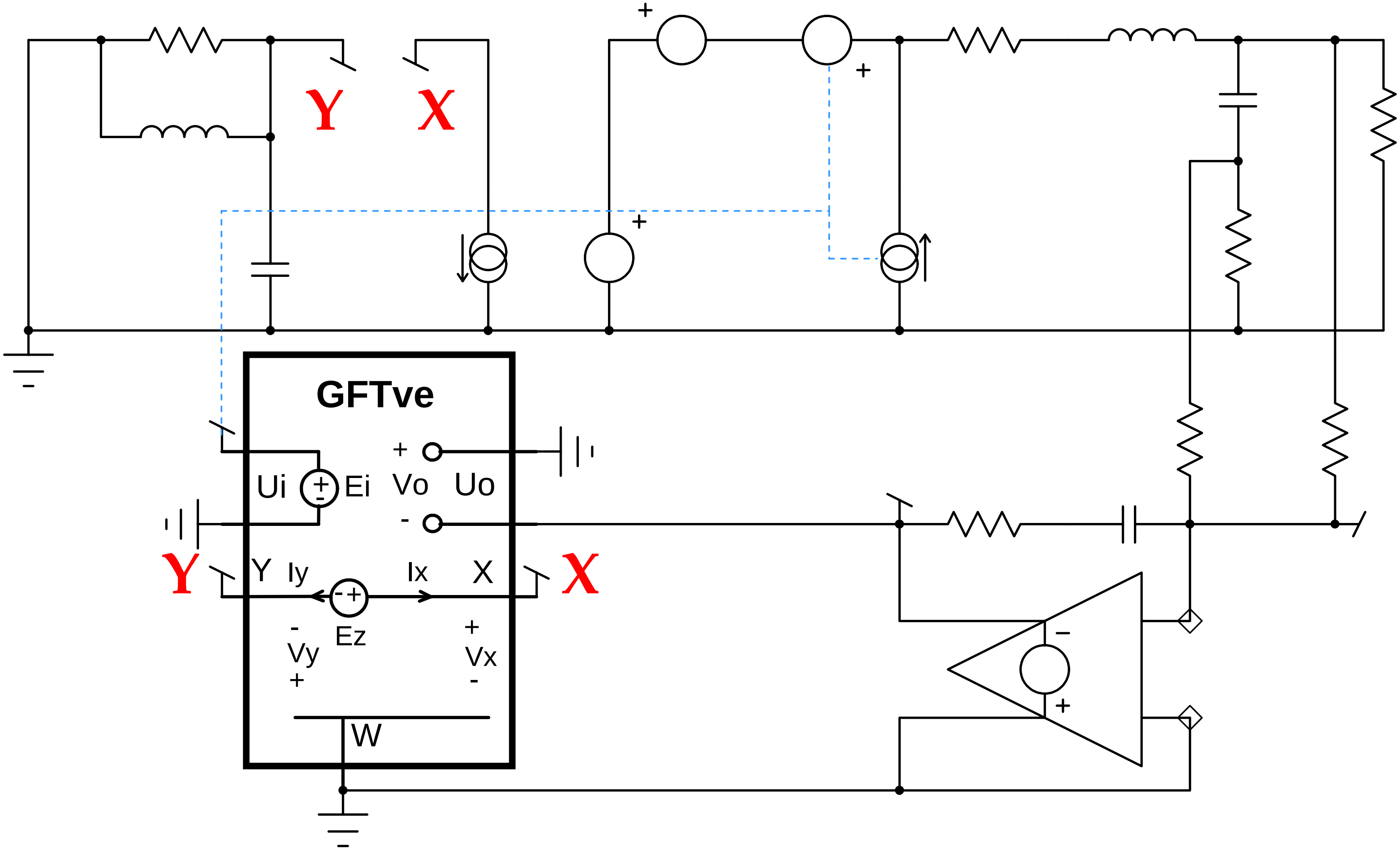


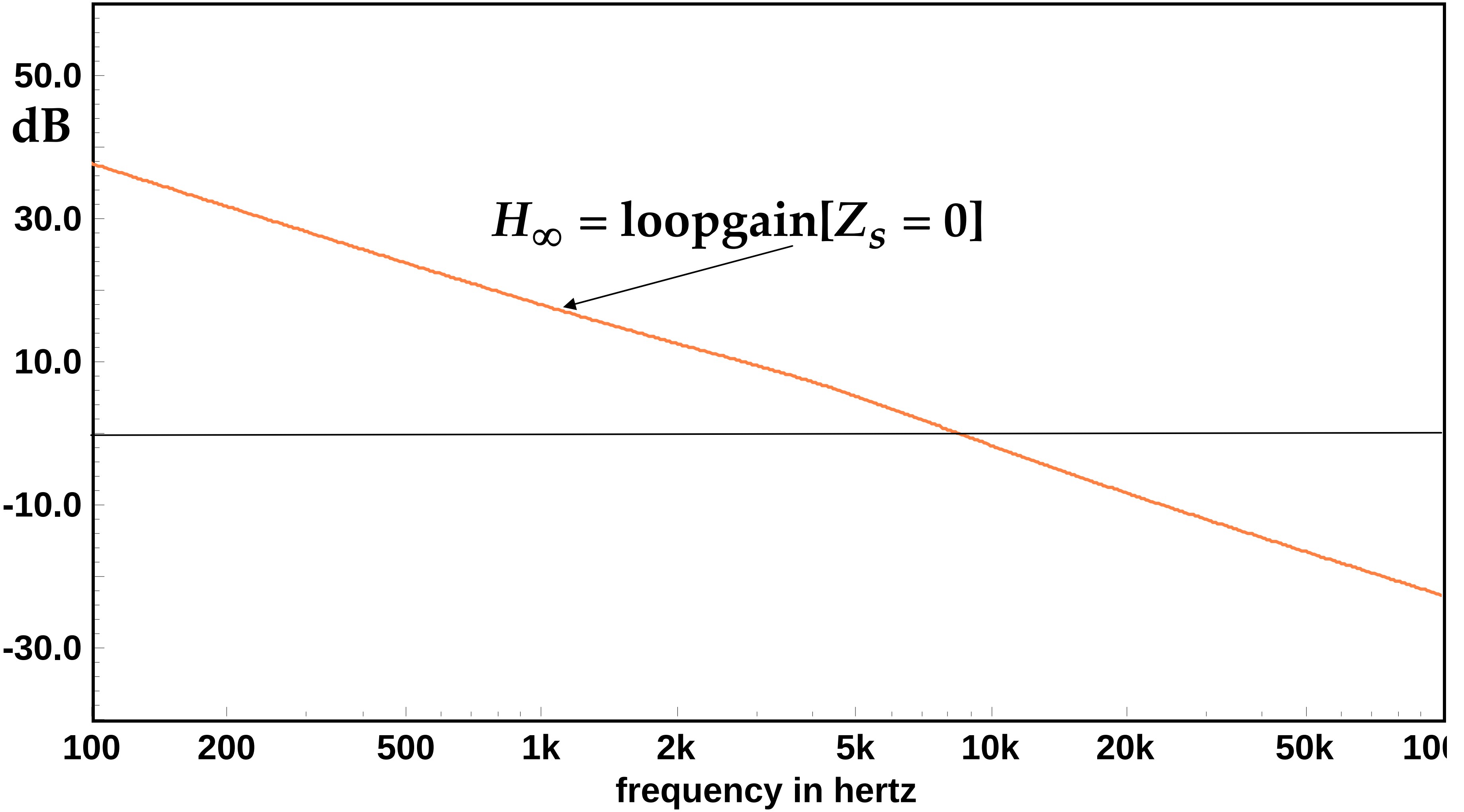
45.0
dB
35.0
ref
1Ω
25.0
15.0
5.00
Z_n
Z_d
100
200
500
1k
2k
5k
10k
20k
50k
100
frequency in hertz

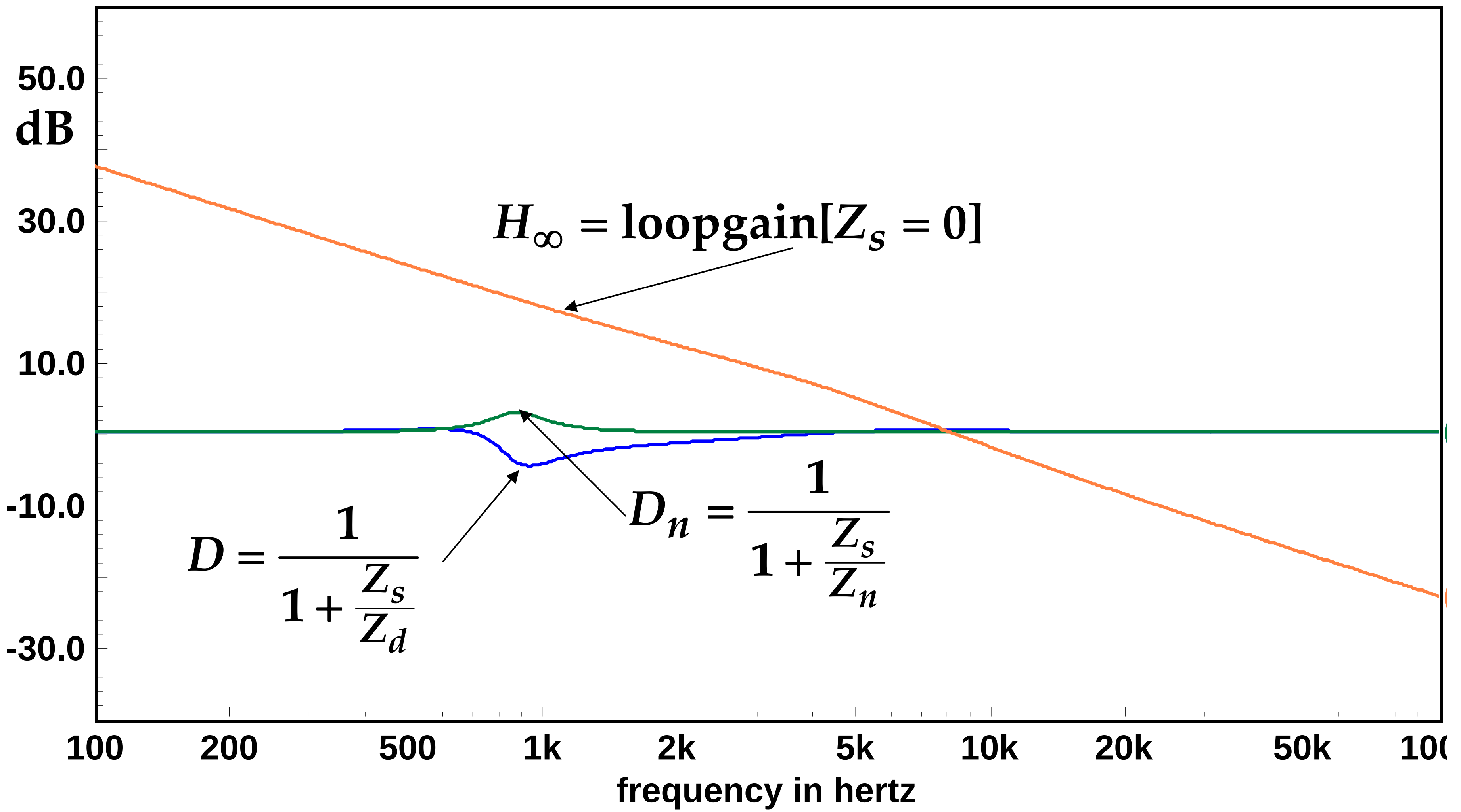


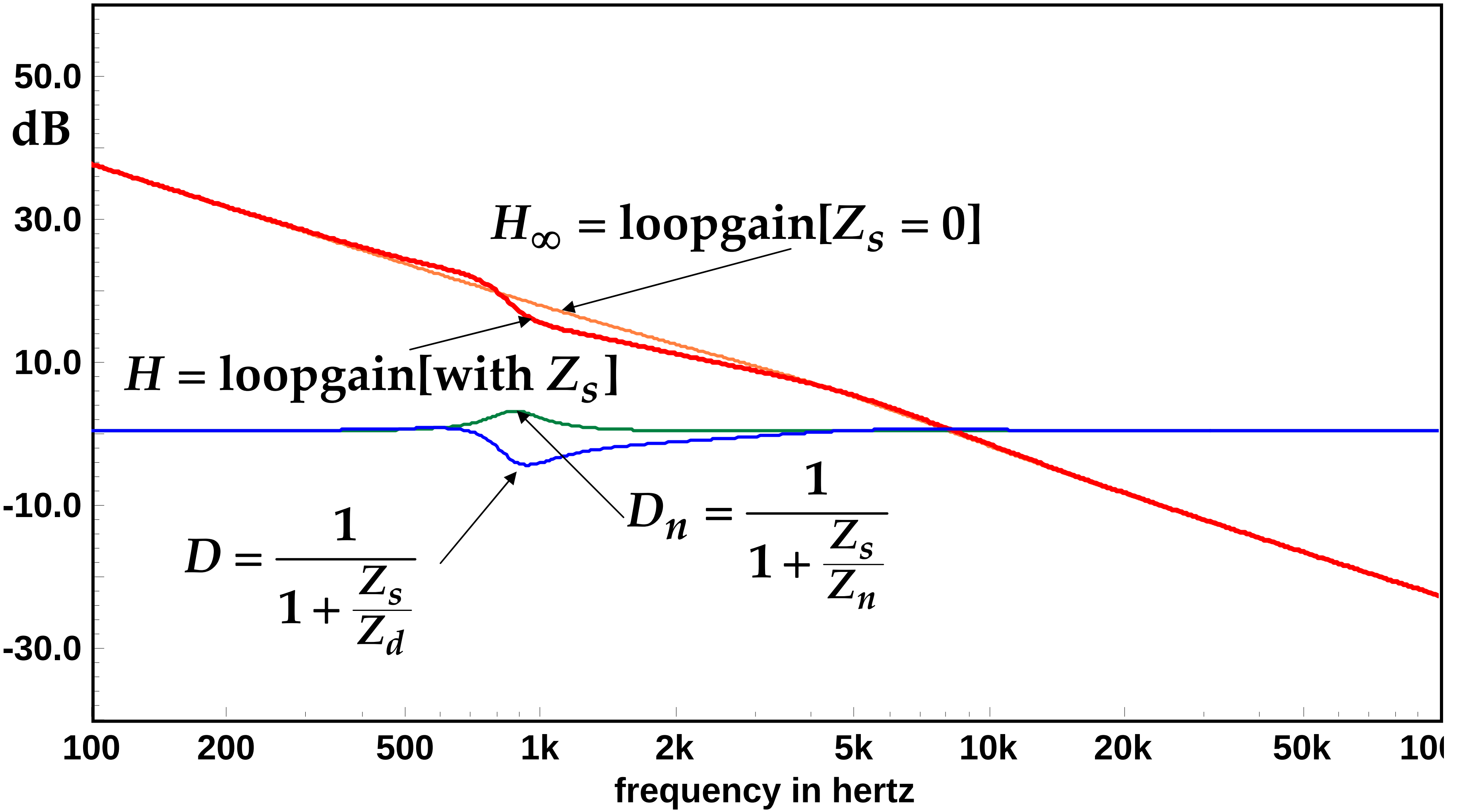
Values as in 1976 Paper Fig. 17, Filter B


45.0
dB
35.0
ref
1Ω
25.0
15.0
5.00
Z_n
Z_d
Z_s
3
100
200
500
1k
2k
5k
10k
20k
50k
100
frequency in hertz


Y
X
GFTve
Ui
Ei
Vo
Uo
Y
Iy
Ix
X
Ez
Vy
Vx
W


50.0
dB
30.0
10.0
-10.0
-30.0
$H_\infty = \text{loopgain}[Z_s = 0]$
100
200
500
1k
2k
5k
10k
20k
50k
frequency in hertz


50.0
dB
30.0
10.0
-10.0
-30.0
$H_\infty = \text{loopgain}[Z_s = 0]$
$D_n = \frac{1}{1+\frac{Z_s}{Z_n}}$
$D = \frac{1}{1+\frac{Z_s}{Z_d}}$
100
200
500
1k
2k
5k
10k
20k
50k
frequency in hertz


50.0
dB
30.0
10.0
-10.0
-30.0
H_∞ = loopgain[$Z_s = 0$]
H = loopgain[with Z_s]
$D_n = \frac{1}{1+\frac{Z_s}{Z_n}}$
$D = \frac{1}{1+\frac{Z_s}{Z_d}}$
100
200
500
1k
2k
5k
10k
20k
50k
frequency in hertz