Proof of general form, equation 11

(4)

$$Z_{probe} = \frac{R\frac{1}{j\omega C_p}}{R + \frac{1}{j\omega C_p}} + j\omega L_C + \frac{Z_L\frac{1}{j\omega C_C}}{Z_L + \frac{1}{j\omega C_C}}$$

($+j\omega L_C$ ignored)

$$= \frac{R}{Rj\omega C_p + 1} + j\omega L_C + \frac{Z_L}{Z_L j\omega C_C + 1}$$

($+j\omega L_C$ ignored)

let $Z_L = \frac{R_L\frac{1}{j\omega C_L}}{R_L + \frac{1}{j\omega C_L}} = \frac{R_L}{R_L j\omega C_L + 1}$

Sub Z_L, $\frac{R}{j\omega C_p R+1} + \frac{\frac{R_L}{j\omega R_L C_L + 1}}{\frac{R_L}{j\omega R_L C_L+1} j\omega C_C + 1}$

$$= \frac{R}{j\omega C_p R+1} + \frac{R_L}{R_L j\omega C_C + j\omega R_L C_L + 1} = \frac{R(R_L j\omega C_C + j\omega R_L C_L + 1) + R_L(j\omega C_p R+1)}{(R_L j\omega C_C + j\omega R_L C_L + 1)(j\omega C_p R+1)}$$

$$= \frac{R(j\omega R_L C_L + 1) + R_L(j\omega C_p R + 1)}{(j\omega R_L C_L + 1)(j\omega C_p R + 1)} = \frac{(R+R_L)\left[1 + \frac{j\omega}{\left(\frac{R+R_L}{RR_L(C_L+C_p)}\right)}\right]}{\left(1 + \frac{j\omega}{\frac{1}{R_L C_L}}\right)\left(1 + \frac{j\omega}{\frac{1}{RC_p}}\right)}$$

(6) General form eq 15

$$\frac{\frac{R_x\frac{1}{j\omega C_x}}{R_x + \frac{1}{j\omega C_x}}}{\frac{R_x\frac{1}{j\omega C_x}}{R_x + \frac{1}{j\omega C_x}} + \frac{R_p\frac{1}{j\omega C_p}}{R_p + \frac{1}{j\omega C_p}}} = \frac{\frac{R_x}{j\omega C_x R_x + 1}}{\frac{R_x}{j\omega C_x R_x + 1} + \frac{R_p}{j\omega R_p C_p + 1}} = \frac{\frac{R_x}{j\omega C_x R_x + 1}}{\frac{R_x(j\omega R_p C_p + 1) + R_p(j\omega C_x R_x)}{(j\omega C_x R_x + 1)(j\omega R_p C_p + 1)}}$$

$$= \frac{R_x(j\omega R_p C_p + 1)}{R_x(j\omega R_p C_p + 1) + R_p(j\omega C_x R_x)} = \frac{R_x}{R_x + R_p}\,\frac{\left(1 + \frac{j\omega}{\frac{1}{R_p C_p}}\right)}{1 + \frac{j\omega}{\frac{R_x + R_p}{R_x R_p (C_p + C_x)}}}$$

pg 320

(7)

$$Z_{probe} = \frac{R}{1 + j\omega RC_p} + 50 = \frac{R + 50\,(1 + j\omega RC_p)}{1 + j\omega RC_p} = \frac{R + 50 + 50 j\omega RC_p}{1 + j\omega RC_p}$$

$$= (R+50)\,\frac{\left(1 + \frac{j\omega}{\frac{R+50}{50RC_p}}\right)}{1 + \frac{j\omega}{\frac{1}{RC_p}}} \checkmark$$

(8) pg 321

$$f_{break} = \frac{1}{2\pi(450)(1\,pF)} = 354\ MHz$$

Chapter 15 Equation 8 & 9

$j := \sqrt{-1}$

$R := 50$

$C := 1 \cdot 10^{-12}$

$$z(w) := \frac{R}{1 + j \cdot w \cdot R \cdot C} + 50$$

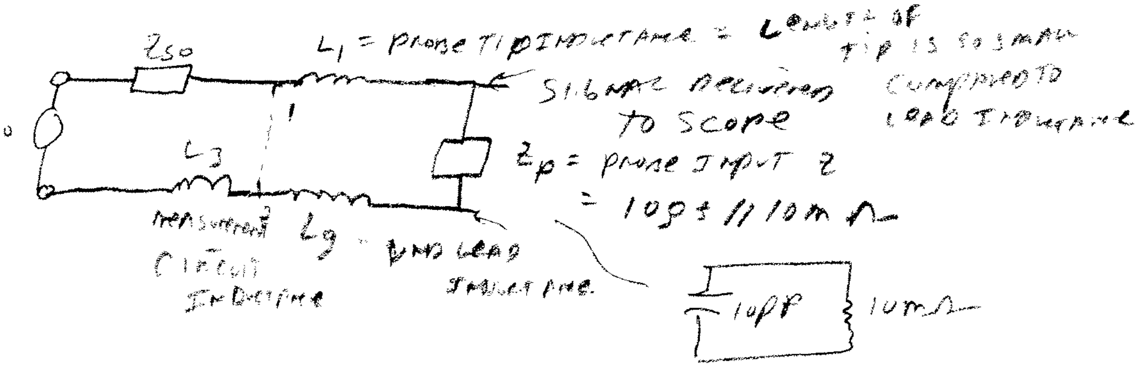
$z(10) = 100 - 2.5i \times 10^{-[illegible]}$ (9)

$z\left(10^{12}\right) = 50.02 - i$ (10)

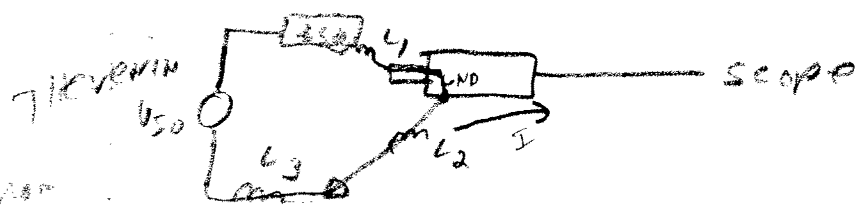
older problem

SECTION 14: PROBES

(10) PASSIVE HIGH Z PROBE:



15" - TOTAL LENGTH OF 3 INDUCTANCES
- PORTION OF INDUCTANCE DUE TO PROBE TIP IS VERY SMALL



FROM F CIRCUIT

L_1 PROBE TIP ACCOUNTS ≈ 3" OF LEAD LENGTH
L_2 GND LEAD INDUCTANCE 6" OF LEAD LENGTH
L_3 INDUCTANCE DUE TO CONDUCTORS IN CIRCUIT TO BE MEASURED.

L_g IS LUMPED AS L_1, L_2, L_3 - IN PROBLEM 15"
SO THE TOTAL PATH LENGTH FORMING L_g IS 15"

$L_g = 15" \times 20nH/in = 300nH$

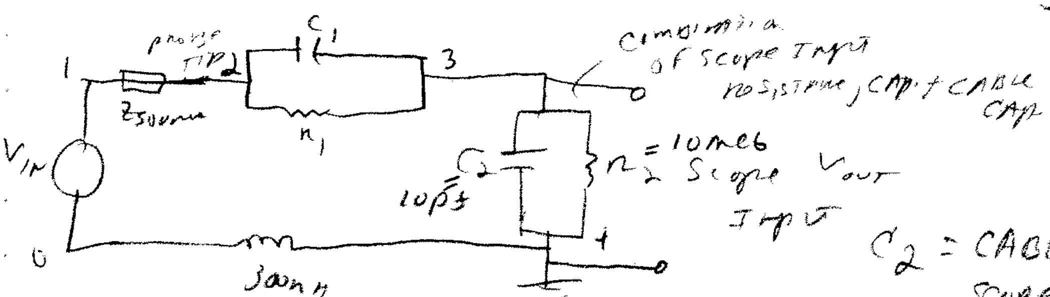
* VOLTAGE ACROSS Z_p IS SIGNAL DELIVERED TO SCOPE FOR DISPLAY
* PROBE RESONANCE EXISTS DUE TO CAPACITANCE POTENTIAL
* Z_{SO} IS LOW (10Ω) WON'T PROVIDE MUCH DAMPING

↗ WITH R_{series} = 300Ω

(3) FINALLY, PLOT 3 SHOWS THE RESPONSE DAMPED EVEN FURTHER. HOWEVER, THIS SHOULD BE AVOIDED BECAUSE OVERDAMPING HAS OCCURRED AND VOLTAGE READING WILL BE VERY INCORRECT. THE ATTENUATION IS MAJOR, ACTUALLY LOSING VOLTAGE AT LOWER FREQUENCIES AS WELL

* TO COMPENSATE PROBE, MOST PROBES, HOWEVER USE AN RC COMBINATION TO OBTAIN THE 10:1 VOLTAGE OUTPUT ACROSS THE ENTIRE PROBE'S BANDWIDTH;

(SO PROBE CAN BE USED IN DIFFERENT SCOPES!)



C_2 = CABLE CAP. SCOPE INPUT CAP.

~~BUT~~

$$\frac{V_{OUT}}{V_{IN}} = \left(\frac{R_2}{R_2 + R_1\left[\frac{1 + s \cdot C_2 \cdot R_2}{1 + s \cdot C_1 \cdot R_1}\right]} \right)$$

$\tau_2 = R_2 C_2 = 0.1$ msec

$\tau_1 = R_1 C_1 =$

IF $R_2 C_2 = R_1 C_1$

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_2}{R_2 + R_1}$$

– FREQUENCY INDEPENDENT RESPONSE

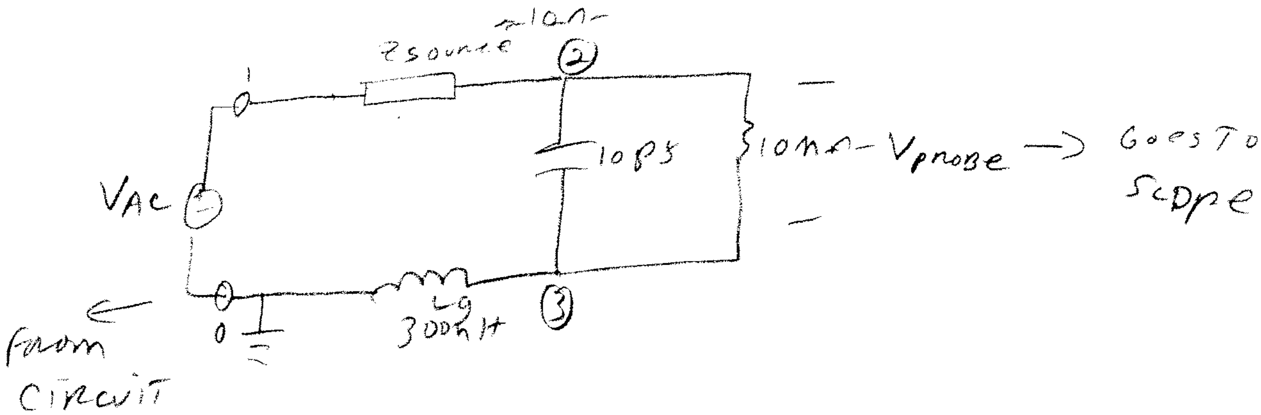
– PROPER COMPENSATION

~~[illegible]~~

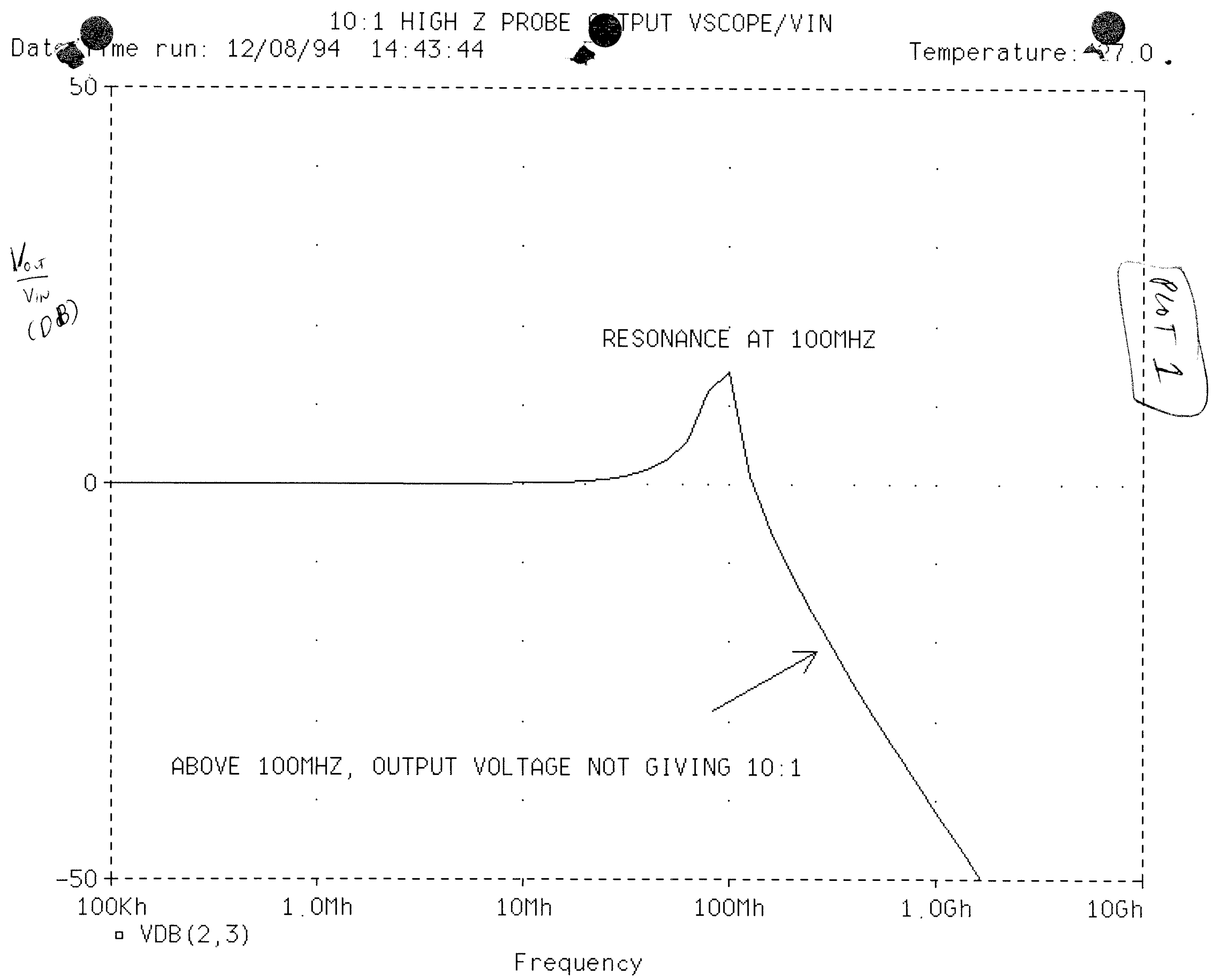
*IF DIFFERENT SCOPE BEING USED, DIFFERENT INPUT Z, THEN YOU WOULD HAVE TO ADJUST RC NETWORK TO OBTAIN TIME CONSTANT $\tau_2 = \tau_1$

Ken Kaiser

```
SECTION 14:PROBES - PROBLEM 10
*[redacted]
*DISPLAY OF VOLTAGE RESPONSE ENTERING SCOPE
VIN 1 0 10 AC 1
R[illegible]1 2 10
C[illegible]3 10P
LG 3 0 300N
RL 2 3 10MEG
*SCOPE INPUT Z IS PARALLEL COMBO OF C1 AND RL
.AC DEC 10 0.1MEG 10G
.PLOT AC VDB(2,3)
.WIDTH OUT=80
.END
```



$$\frac{V_{out}}{V_{in}} = \frac{V_{probe}}{V_{AC}} \text{ in dB}$$


10:1 HIGH Z PROBE OUTPUT VSCOPE/VIN
Date/Time run: 12/08/94 14:43:44
Temperature: 27.0
PLOT 1
Vout/Vin (DB)
50
0
-50
RESONANCE AT 100MHZ
ABOVE 100MHZ, OUTPUT VOLTAGE NOT GIVING 10:1
100Kh
1.0Mh
10Mh
100Mh
1.0Gh
10Gh
VDB(2,3)
Frequency

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```
SECTION 14:PROBES - PROBLEM 10
*[redacted]
*DISPLAY OF VOLTAGE RESPONSE ENTERING SCOPE
VIN 1 0 10 AC 1
R[illegible] 1 2 10
R[illegible] 3 100
*RD IS ADDED SERIES RESISTANCE TO DAMPEN RESPONSE - DECREASE Q
C1 3 4 10P
LG 4 0 300N
RL 3 4 10MEG
*SCOPE INPUT Z IS PARALLEL COMBO OF C1 AND RL
.AC DEC 10 0.1MEG 10G
.PLOT AC VDB(2,3)
.WIDTH OUT=80
.END
```

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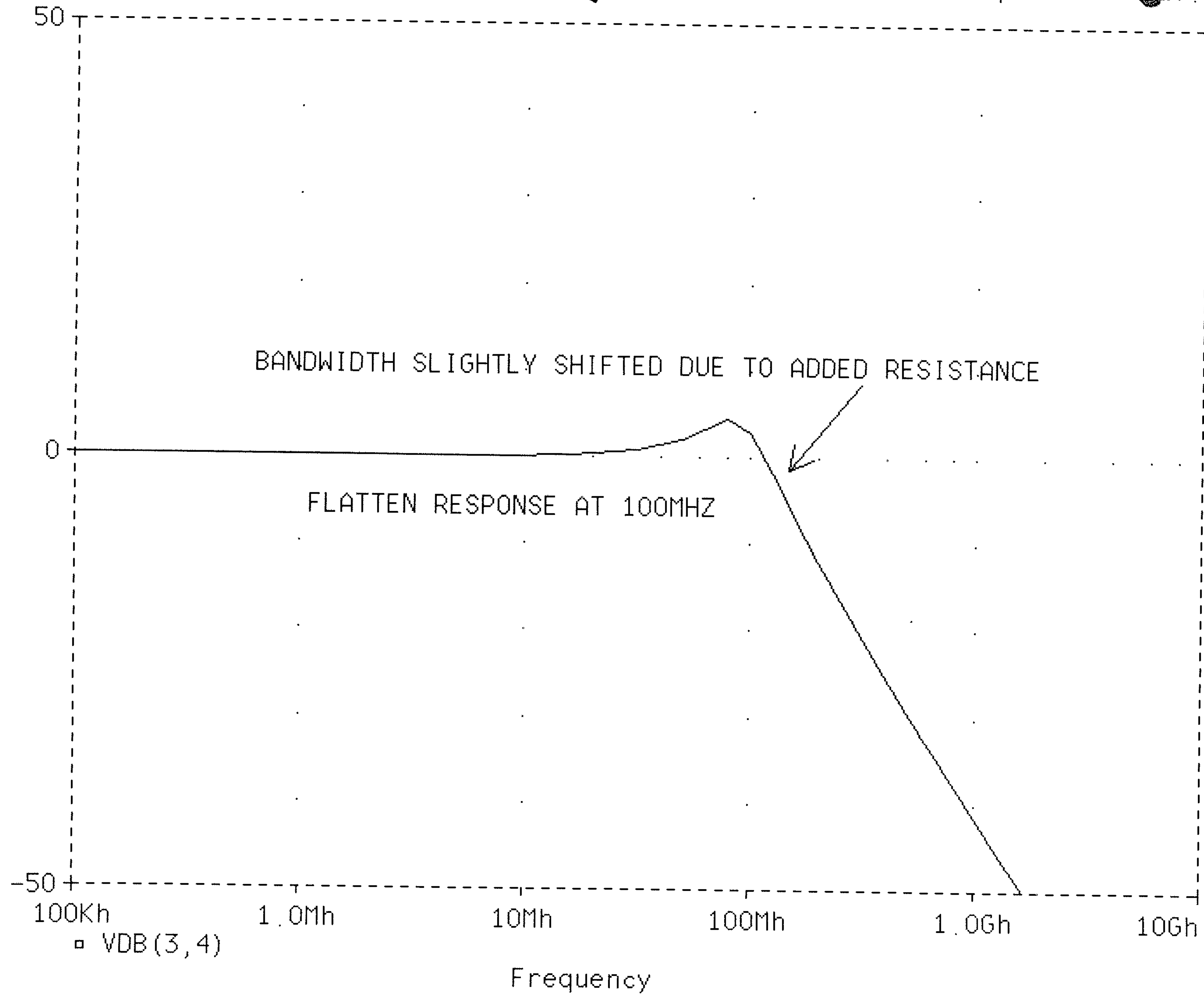
PLOT 2

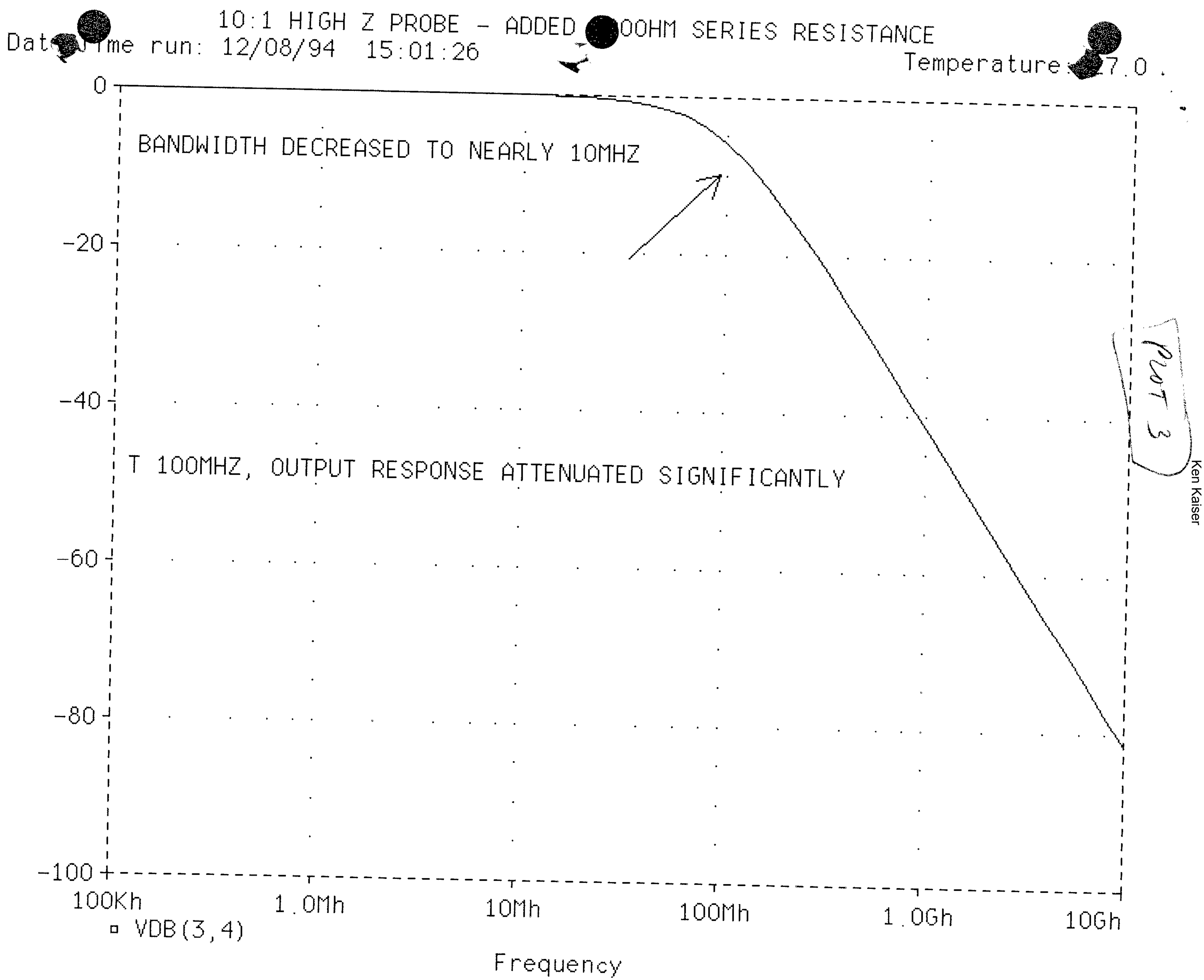
10:1 HIGH Z PROBE - ADDED [illegible]00OHM SERIES RESISTANCE

Date/Time run: 12/08/94 14:53:27 Temperature: [illegible]7.0



Ken Kaiser

```
SECTION 14:PROBES - PROBLEM 10
*[redacted]
*DISPLAY OF VOLTAGE RESPONSE ENTERING SCOPE
VIN 1 0 10 AC 1
R[illegible] 1 2 10
RD [illegible] 3 300
*RD IS ADDED SERIES RESISTANCE TO DAMPEN RESPONSE - DECREASE Q
*HOWEVER, THIS COMBINATION CAUSES OVERDAMPING - BANDWIDTH LOST
C1 3 4 10P
LG 4 0 300N
RL 3 4 10MEG
*SCOPE INPUT Z IS PARALLEL COMBO OF C1 AND RL
.AC DEC 10 0.1MEG 10G
.PLOT AC VDB(2,3)
.WIDTH OUT=80
.END
```

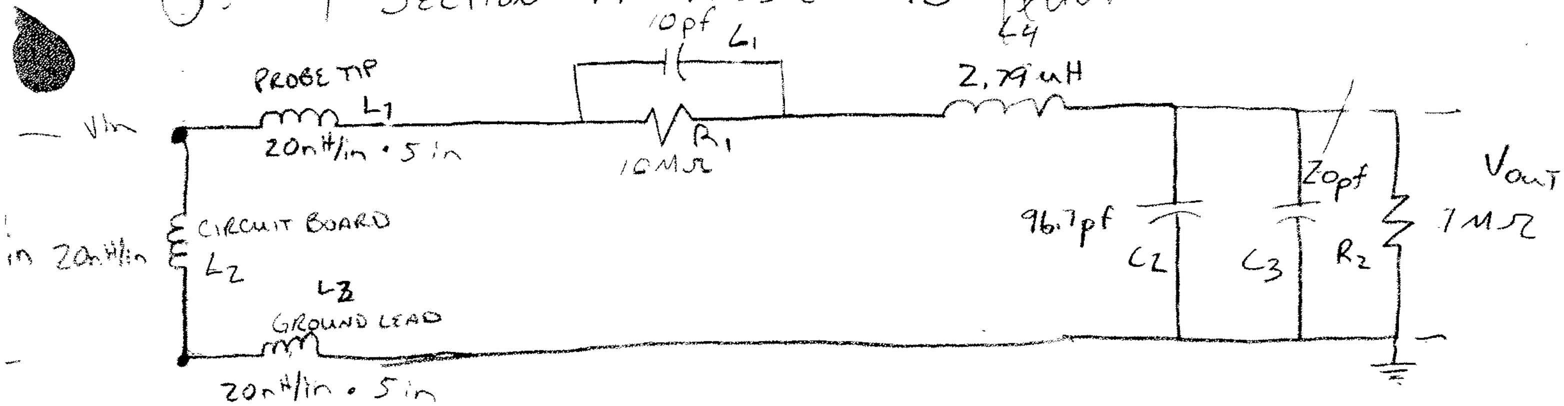

10:1 HIGH Z PROBE - ADDED
00OHM SERIES RESISTANCE
12/08/94 15:01:26
Temperature
BANDWIDTH DECREASED TO NEARLY 10MHZ
T 100MHZ, OUTPUT RESPONSE ATTENUATED SIGNIFICANTLY
0
-20
-40
-60
-80
-100
100Kh
1.0Mh
10Mh
100Mh
1.0Gh
10Gh
VDB(3,4)
Frequency
PLOT 3
Ken Kaiser

[redacted]

Ken Kaiser

old problem adding extra L in lead!

SECTION 14 PROBLEM 10



1 meter of cable is electrically small for frequencies less than:

$f = \frac{v}{\lambda} = v/1\text{meter}$

characteristic impedance = 170 Ω $\quad Z_0 = \sqrt{L/C} \quad L = C Z_0^2$

CAPACITANCE OF LINE = 96.7 pF/m

$L = 2.79\ \mu H/m \qquad v = \frac{1}{\sqrt{LC}} = ~~6\times10^7~~ m/sec$

$f = \frac{60\times10^6}{1} = 60\ MHz$

★ ELECTRICALLY SMALL FOR FREQUENCIES LESS THAN 6 MHZ

$~~V~~ = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{\mu\epsilon}}$

$$\frac{V_{out}}{V_{in}} = \frac{1M\Omega \,||\, \frac{1}{j\omega C_3} \,||\, \frac{1}{j\omega C_2}}{j\omega L_2 + 10M\Omega \,||\, \frac{1}{j\omega C_1} + j\omega L_4 + 1M\Omega \,||\, \frac{1}{j\omega C_3} \,||\, \frac{1}{j\omega C_2} + j\omega}$$

ON SCOPE SIDE USE NETWORK THAT CONTAINS TIME CONSTANT ADJUSTMENTS WITH INDUCTIVE PEAKING.

$R1 := 10\cdot 10^{6}$ $\quad C1 := 10\cdot 10^{-12}$ $\quad L1 := 100\cdot 10^{-9}$ Ken Kaiser $\quad j := \sqrt{-1}$

$R2 := 1\cdot 10^{6}$ $\quad C2 := 96.7\cdot 10^{-12}$ $\quad L2 := 100\cdot 10^{-9}$ $\quad x := 10, 10.1 .. 80$

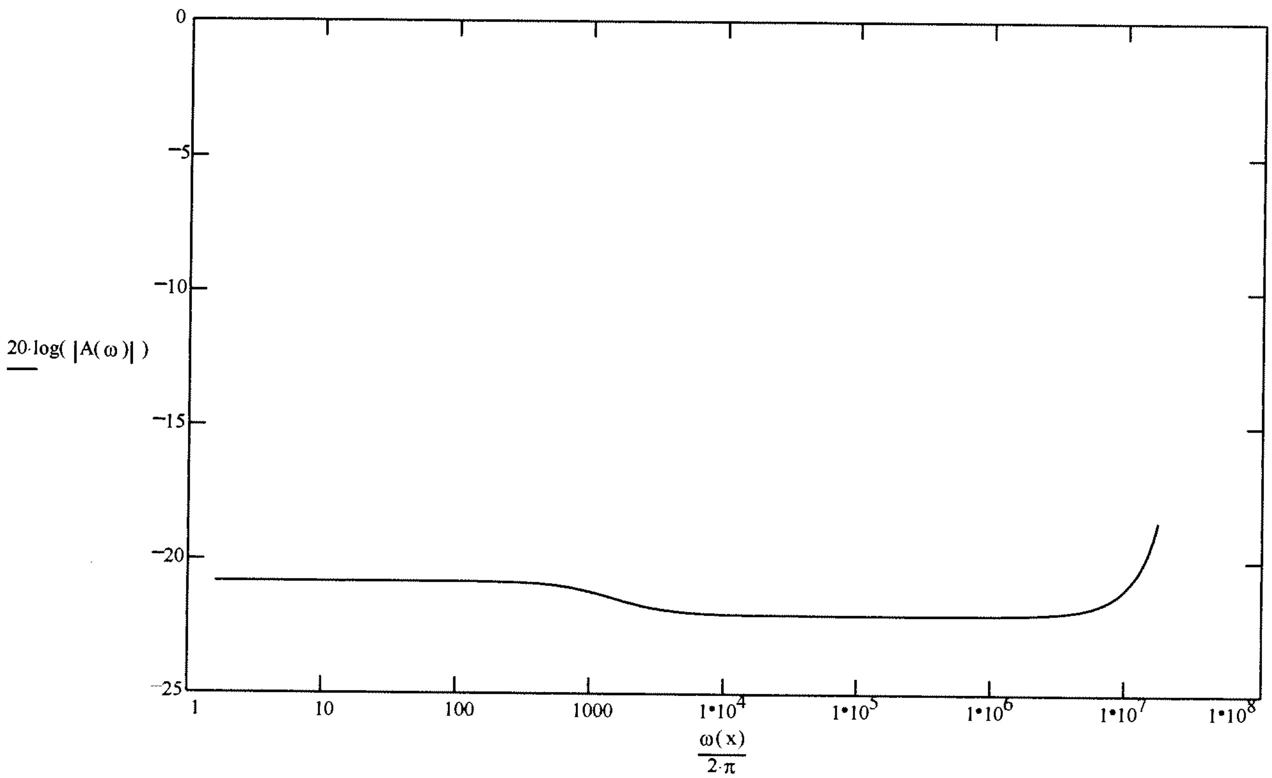
$C3 := 20\cdot 10^{-12}$ $\quad L3 := 2.79\cdot 10^{-6}$

$$\omega(x) := \left[(x+1) - 10\cdot \mathrm{floor}\left(\frac{x}{10}\right)\right]\cdot 10^{\mathrm{floor}\left(\frac{x}{10}\right)}$$

$$Zpar(\omega) := \frac{1}{\left(\frac{1}{R2}\right) + j\cdot\omega(x)\cdot C3 + j\cdot\omega(x)\cdot C2}$$

$$Zprobe(\omega) := \frac{R1\cdot\frac{1}{j\cdot\omega(x)\cdot C1}}{R1 + \frac{1}{j\cdot\omega(x)\cdot C1}}$$

$$A(\omega) := \frac{Zpar(\omega)}{j\cdot\omega(x)\cdot L1 + Zprobe(\omega) + j\cdot\omega(x)\cdot L3 + Zpar(\omega) + j\cdot\omega(x)\cdot L2}$$



$R1 := 10 \cdot 10^{6}$ $\quad C1 := 10 \cdot 10^{-12}$ $\quad L1 := 100 \cdot 10^{-9}$ Ken Kaiser $\quad j := \sqrt{-1}$

$R2 := 1 \cdot 10^{6}$ $\quad C2 := 96.7 \cdot 10^{-12}$ $\quad L2 := 100 \cdot 10^{-9}$ $\quad x := 20, 20.1 .. 80$

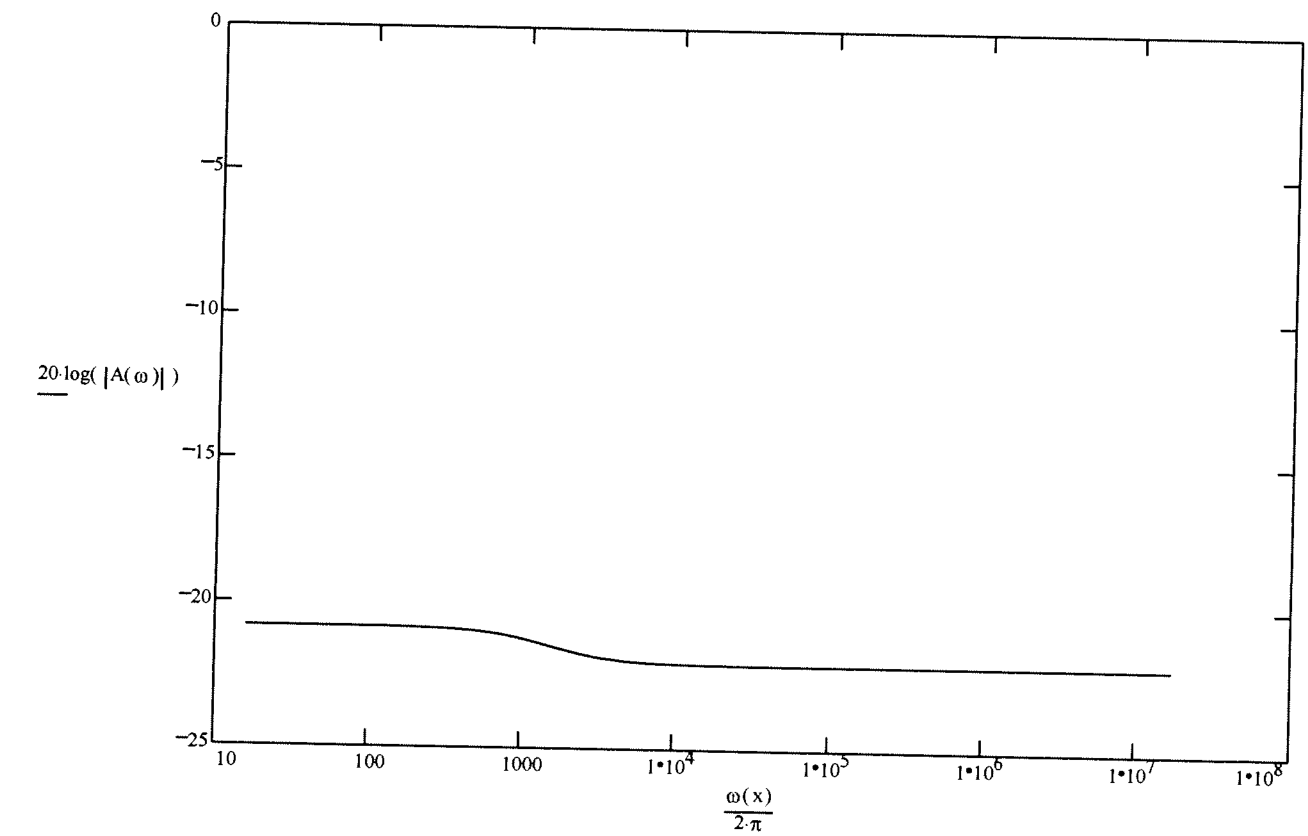
$C3 := 20 \cdot 10^{-12}$ $\quad L3 := 2.79 \cdot 10^{-6}$

$Lcomp := 0.256 \cdot 10^{-6}$ $\quad \omega(x) := \left[(x+1) - 10 \cdot \mathrm{floor}\left(\frac{x}{10}\right)\right] \cdot 10^{\mathrm{floor}\left(\frac{x}{10}\right)}$

$$Zpar(\omega) := \frac{1}{\left(\frac{1}{R2}\right) + j \cdot \omega(x) \cdot C3 + j \cdot \omega(x) \cdot C2} + j \cdot \omega(x) \cdot Lcomp$$

$$Zprobe(\omega) := \frac{R1 \cdot \frac{1}{j \cdot \omega(x) \cdot C1}}{R1 + \frac{1}{j \cdot \omega(x) \cdot C1}}$$

$$A(\omega) := \frac{Zpar(\omega)}{j \cdot \omega(x) \cdot L1 + Zprobe(\omega) + j \cdot \omega(x) \cdot L3 + Zpar(\omega) + j \cdot \omega(x) \cdot L2}$$



Ken Kaiser

$R1 := 10\cdot 10^{6}$ $C1 := 10\cdot 10^{-12}$ $L1 := 100\cdot 10^{-9}$ $j := \sqrt{-1}$

$R2 := 1\cdot 10^{6}$ $C2 := 96.7\cdot 10^{-12}$ $L2 := 100\cdot 10^{-9}$ $x := 20, 20.1 .. 80$

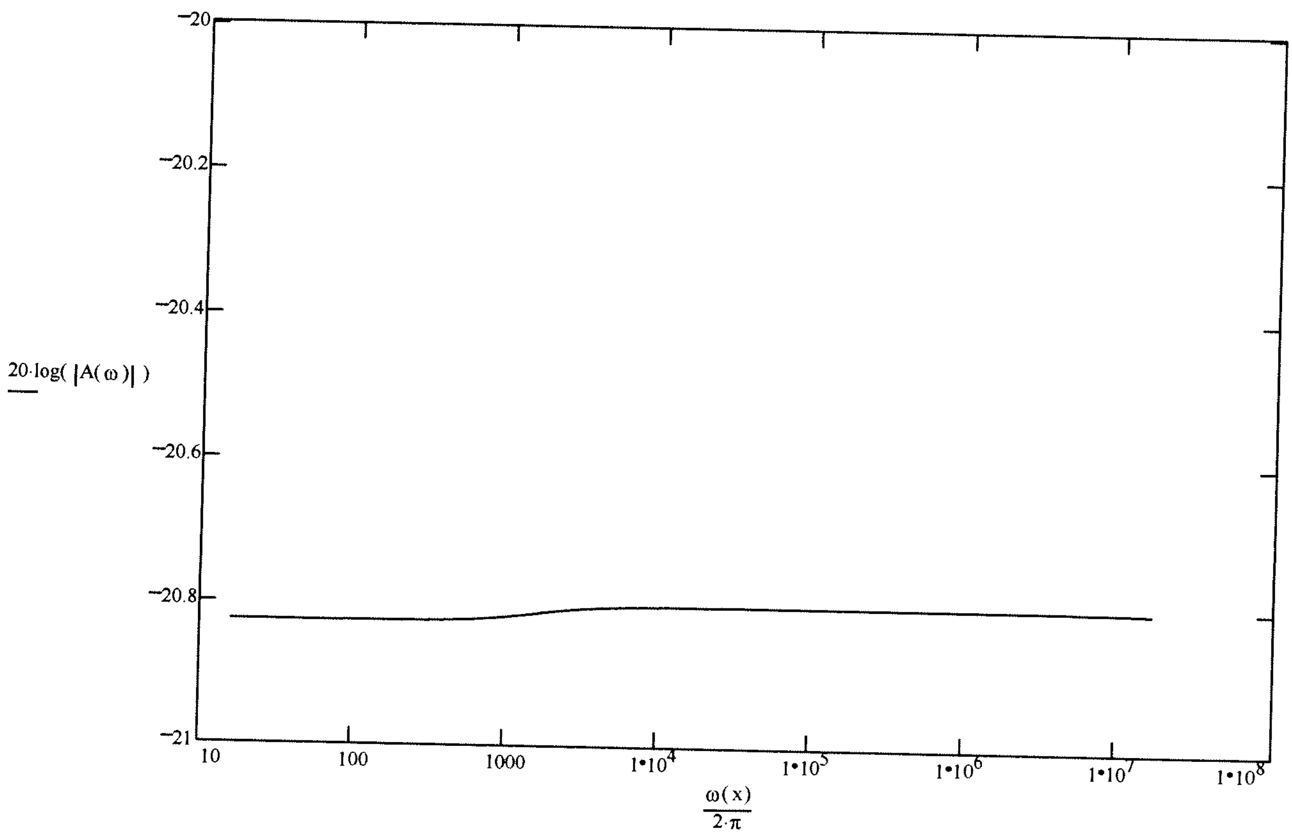
$C3 := 3\cdot 10^{-12}$ $L3 := 2.79\cdot 10^{-6}$

$Lcomp := 0.3\cdot 10^{-6}$ $\omega(x) := \left[(x+1) - 10\cdot \text{floor}\left(\frac{x}{10}\right)\right]\cdot 10^{\text{floor}\left(\frac{x}{10}\right)}$

$$Zpar(\omega) := \frac{1}{\left(\frac{1}{R2}\right) + j\cdot\omega(x)\cdot C3 + j\cdot\omega(x)\cdot C2} + j\cdot\omega(x)\cdot Lcomp$$

$$Zprobe(\omega) := \frac{R1\cdot\frac{1}{j\cdot\omega(x)\cdot C1}}{R1 + \frac{1}{j\cdot\omega(x)\cdot C1}}$$

$$A(\omega) := \frac{Zpar(\omega)}{j\cdot\omega(x)\cdot L1 + Zprobe(\omega) + j\cdot\omega(x)\cdot L3 + Zpar(\omega) + j\cdot\omega(x)\cdot L2}$$



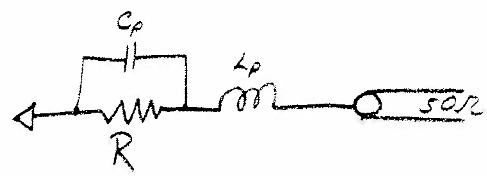
old problem

[redacted]
Section 14
Problem # 9

$R_{50} := 50 \quad R_{250} := 250 \quad C_p := 10 \cdot 10^{-12} \quad j := \sqrt{-1} \quad L_p := 1 \cdot 10^{-9}$

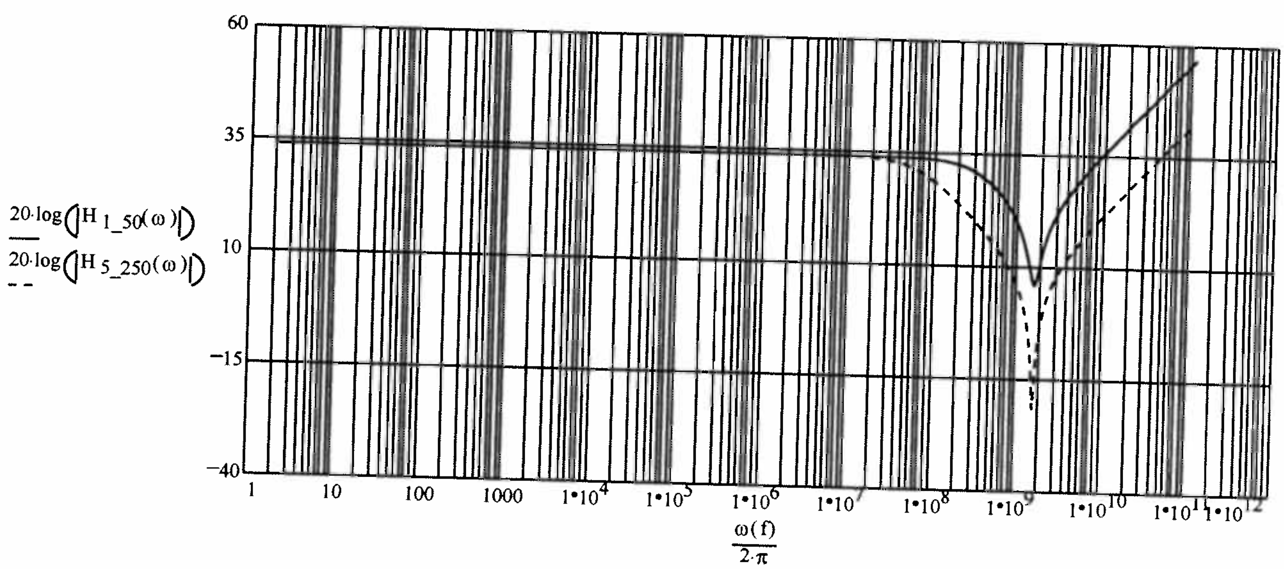
$f := 1, 1.1 .. 110$

$$\omega(f) := 2 \cdot \pi \cdot \left(1 + f - 10 \cdot \text{floor}\left(\frac{f}{10}\right)\right) \cdot 10^{\text{floor}\left(\frac{f}{10}\right)}$$



$$H_{1\_50}(\omega) := \frac{R_{50}}{R_{50} \cdot j \cdot \omega(f) \cdot C_p + 1} + L_p \cdot j \cdot \omega(f)$$

$$H_{5\_250}(\omega) := \frac{1}{5} \cdot \left(\frac{R_{250}}{R_{250} \cdot j \cdot \omega(f) \cdot C_p + 1} + L_p \cdot j \cdot \omega(f)\right)$$



Putting the five resistors in parallel has no real affect on the frequency response of the system.

The magnitude of the impedance does decrease a little faster when the five resistors are put in parallel, but it is not a significant amount.