Ch. 6. EMI Filter Design

2018-2019 3.

3. A common-mode (CM) filter is needed to suppress conducted noise emission from a switched mode power supply (SMPS). The equivalent CM noise source impedance of the SMPS can be modelled with a capacitance of 100 pF. As the conducted noise emission will be measured through a line impedance stabilization network LISN, the noise termination impedance can be modelled with a 25 Ω resistance. Design a second-order CM filter with a 2 mH CM inductor (self-resonant frequency 300 kHz) and two 5000 pF capacitors (self-resonant frequency 5 MHz).

Note: Use the impedance graph for your calculation and tie it to your answer booklet with the string.

(a) Estimate the filter attenuation at 100 kHz, 1 MHz and 10 MHz with the two capacitors added.

(6 Marks)

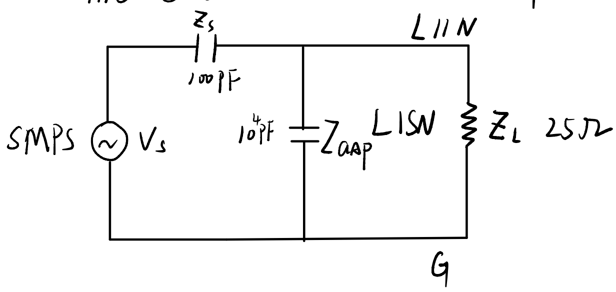
(b) Repeat part (a) with both the CM inductor and the two capacitors added.

(10 Marks)

(c) Draw the final CM filter circuit with the noise source impedance and noise termination impedance clearly indicated.

(4 Marks)

(a) The circuit with the two capacitors added is



$Z_S = \frac{1}{jwC_S}$, where $C_s = 100$ pF, $Z_L = 25\Omega$

$Z_p = Z_s // Z_L$ and plot Z_p on the impedance graph

$Z_{CAP} = 10^4$ pF, with a SRF = 5 MHz

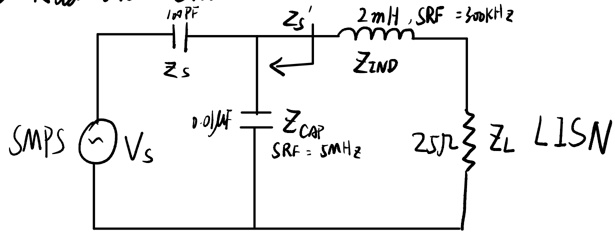
plot Z_{CAP} on the same impedance graph.

Attenuation occurs when $Z_{cap} < Z_P$

From the impedance graph, we get that

Freq.	Attenuation due to C_{AP}
100 KHz	0 dB
1 MHz	28 - 24 = 4 dB
10 MHz	28 - 15 = 13 dB

(b) Add the CM inductor towards the LISN because $Z_{LISN} < Z_s$ in the frequency range of interest.



$Z_s' = Z_s \parallel Z_{CAP}$

$Z_{sum} = Z_s' + Z_L$, plot Z_{sum} on the impedance graph

plot Z_{IND} on the same impedance graph

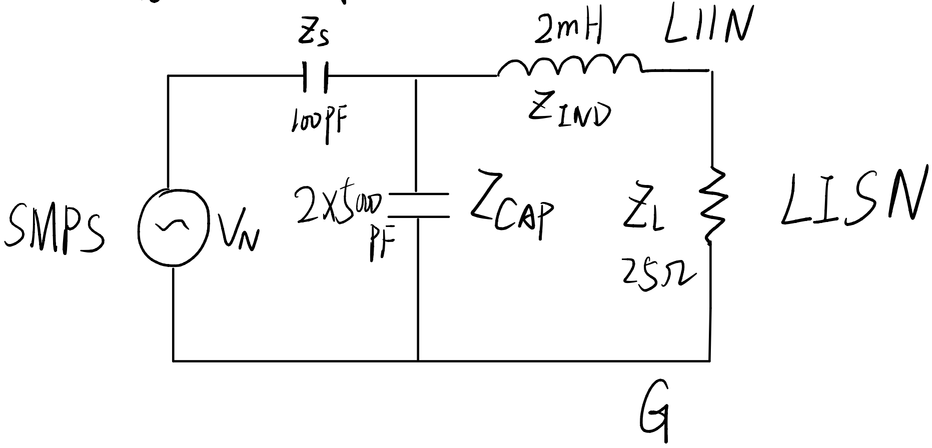
Attenuation occurs when $Z_{IND} > Z_{sum}$

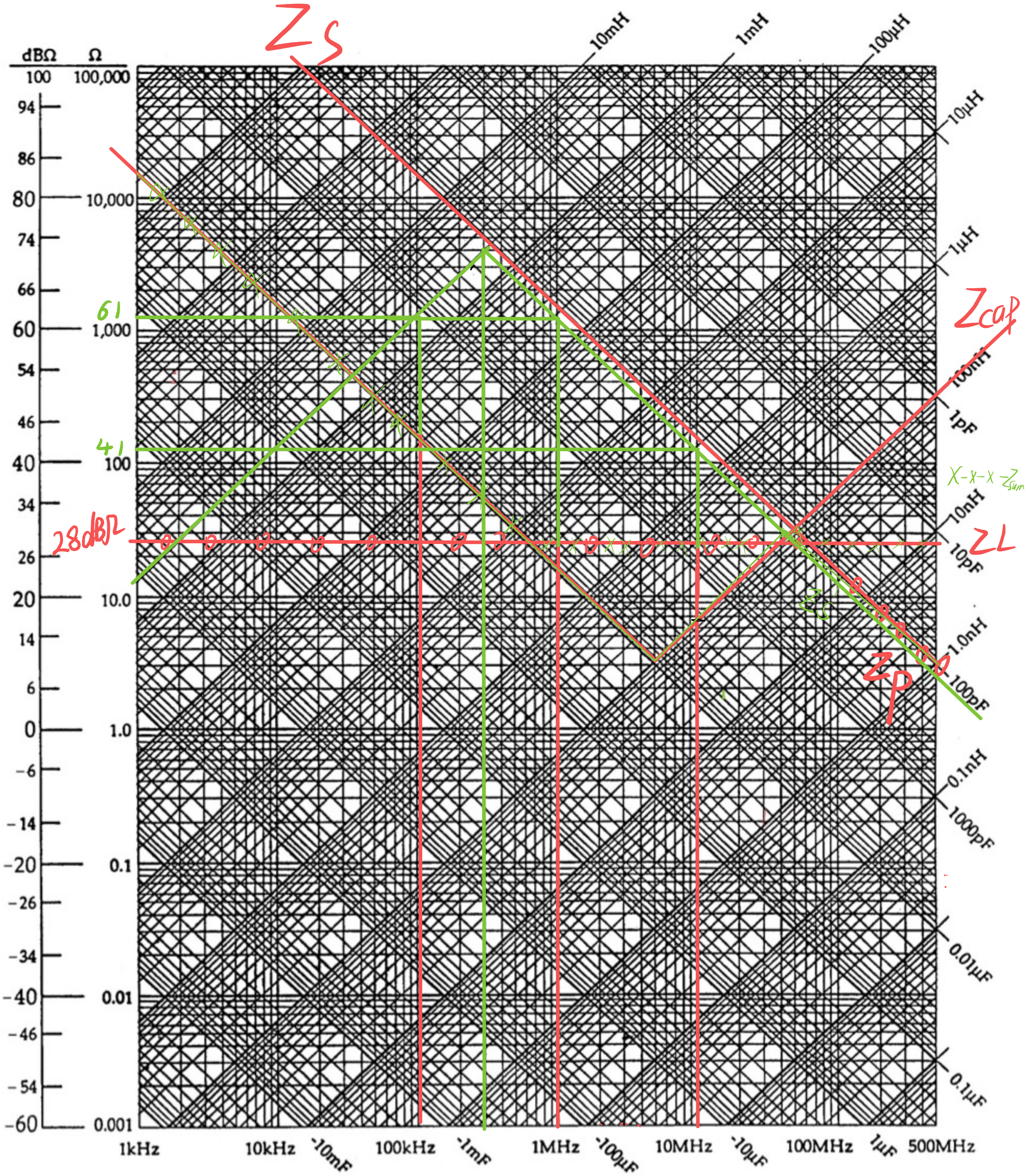
Freq	Attenuation due to inductor
100kHz	61 - 28 = 33 dB
1MHz	61 - 28 = 33 dB
10MHz	41 - 28 = 13 dB

Therefore, the total attenuation

Freq.	A_{CAP}	A_{IND}	A_{total}
100kHz	0	33	33
1MHz	4	33	37
10MHz	13	13	26

(c) Hence, the final CM filter circuit is





Zs
dBΩ
Ω
100
100,000
94
86
80
10,000
74
66
60
1,000
54
46
40
100
34
26
20
10.0
14
6
0
1.0
-6
-14
-20
0.1
-26
-34
-40
0.01
-46
-54
-60
0.001
1kHz
10kHz
10mF
100kHz
1mF
1MHz
100μF
10MHz
10μF
100MHz
1μF
500MHz
10mH
1mH
100μH
10μH
1μH
100nH
1pF
10nH
10pF
1.0nH
100pF
0.1nH
1000pF
0.01μF
0.1μF
61
41
28dBΩ
Zcap
ZL
Zp
X-X-X Zsum

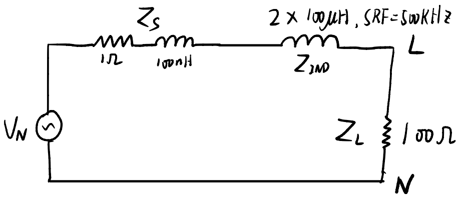
2017 - 2018 2.(b)

(b) A differential-mode (DM) filter is needed between an inverter system and the power grid to block the conducted noise emission generated by the inverter system. The equivalent DM noise source impedance of the inverter system can be modelled as a resistance of 1 Ω in series with an inductance of 100 nH. The impedance looking into the power grid can be modelled as a 100 Ω resistance. Design the DM filter with two 100 μH inductors (self-resonant frequency = 500 kHz) and a 1 μF capacitor (self-resonant frequency = 1 MHz). Use the impedance graphs provided, estimate the filter attenuation at 100 kHz and 10 MHz.

(10 Marks)

Note: After completing your calculation on the impedance graph, please tie it to your answer booklet with the string provided.

Add DM inductors first, the circuit is



$Z_S = R_S + j\omega \times L_S$, where $L_S = 100nH$, $R_S = 1\Omega$

$Z_{sum} = Z_S + Z_L$, $Z_L = 100\Omega$, and plot Z_{sum} on the impedance graph.

plot Z_{IND} ($200\mu H$, SRF=500KHz) on the same graph.

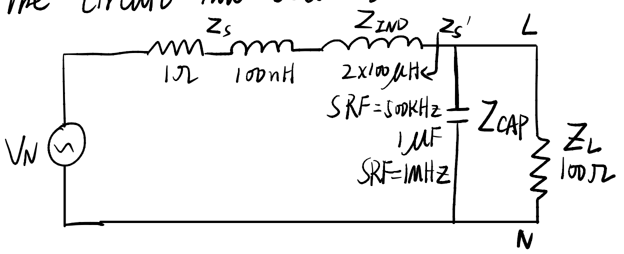
Attenuation occurs when $Z_{IND} > Z_{sum}$.

From the impedance graph,

Freq.	Attenuation due to Inductor
100 KHz	41 - 40 = 1 dB
10 MHz	0

Then adding the shunt capacitor towards the Z_L, because $Z_L > Z_S$ in the frequency range of interest.

The circuit now becomes:



Freq.	Attenuation due to capacitor
100KHz	40 - 3 = 37 dB
10MHz	30 - 3 = 27 dB

$Z_S' = Z_S + Z_{IND}$,

$Z_P = Z_S' \parallel Z_L$, plot Z_P on the impedance graph

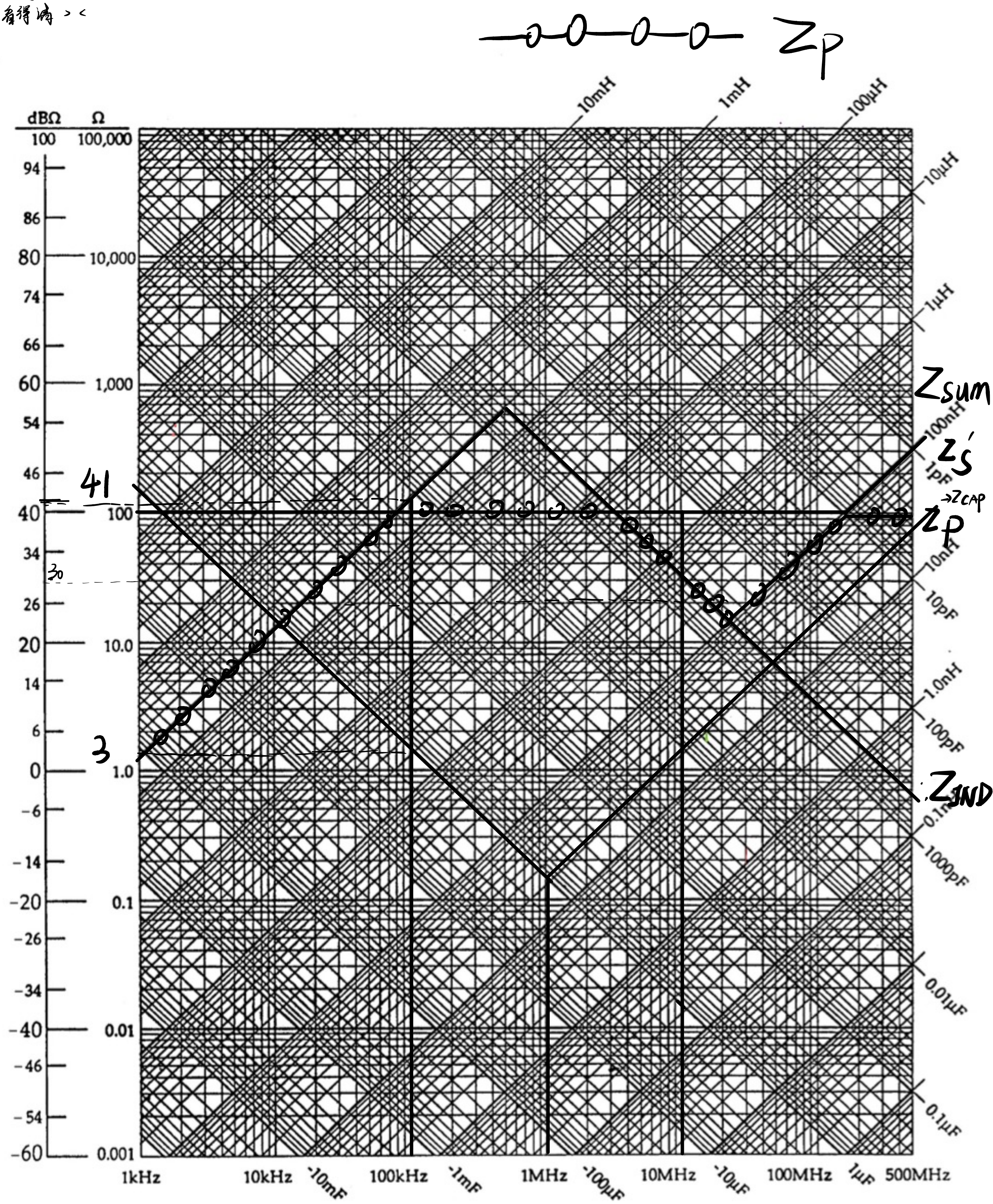
Plot Z_{CAP} ($1\mu F$, SRF=1MHz) on the same impedance graph.

Attenuation occurs when $Z_{CAP} < Z_P$

Hence, the total attenuation is

Freq.	A_{IND}	A_{cap}	A_{total}
100KHz	1	37	38
10MHz	0	27	27

这nm怎么
看得清 > <



Zp
dBΩ
Ω
100
100,000
94
86
80
10,000
74
66
60
1,000
54
46
40
100
34
26
20
10.0
14
6
0
1.0
-6
-14
-20
0.1
-26
-34
-40
0.01
-46
-54
-60
0.001
1kHz
10kHz
100kHz
1MHz
10MHz
100MHz
500MHz
10mF
1mF
100μF
10μF
1μF
10mH
1mH
100μH
10μH
1μH
100nH
1pF
10nH
10pF
1.0nH
100pF
0.1nF
1000pF
0.01μF
0.1μF
41
30
3
Zsum
Z's
→Zcap
Zp
ZIND

2016-2017 3.

3. Figure 5 shows a second-order common-mode (CM) filter to be installed in a switched mode power supply (SMPS) for noise suppression. The SMPS is powered through a line impedance stabilization network (LISN). The equivalent CM noise source impedance of the SMPS can be modelled as a capacitor of 5000 pF. The common-mode inductor (L_{CM}) has a self-resonant frequency (SRF) of 200 kHz and each capacitor (C_Y) has a SRF of 5 MHz.

(a) With L_{CM} alone and without the two C_Y, what is the estimated noise attenuation at 100 kHz, 1 MHz and 10 MHz?

(10 Marks)

(b) With all the components added (L_{CM} and two C_Y), what is the estimated noise attenuation at 100 kHz, 1 MHz and 10 MHz?

(6 Marks)

(c) Comment on the noise attenuations obtained in parts (a) and (b).

(4 Marks)

Note: Use the impedance graph to estimate the filter attenuation and attach it with the answer booklet.

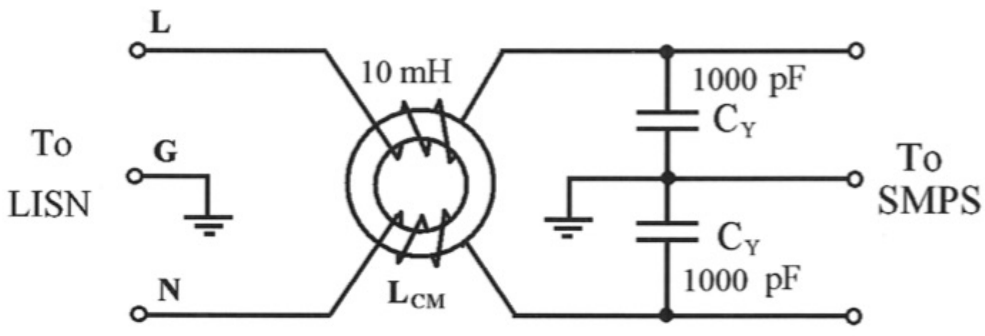
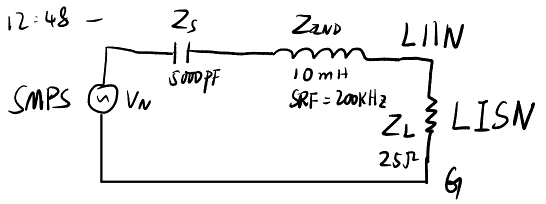


Figure 5

(a) With Lcm only, the circuit is

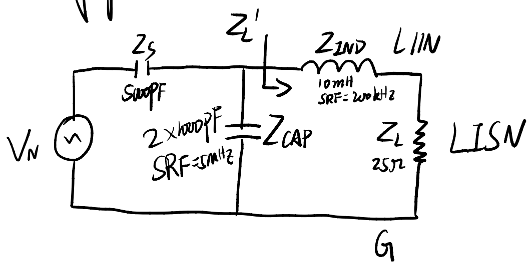
12:48 –



$Z_{sum} = Z_S + Z_L$, plot Z_{sum} on the impedance graph
plot Z_{IND} (10mH, SRF=200kHz) on the same graph

freq	Attenuation due to Inductor
100kHz	76 − 49 = 27 dB
1MHz	69 − 29 = 40 dB
10 MHz	49 − 28 = 21 dB

(b) with all the components added, the two shunt capacitors face towards the source from the figure 5. and circuit is



$$Z_S = \frac{1}{j\omega C_s}$$, where $C_s = 5000pF$

$$Z_L' = Z_{IND} + Z_L,$$

$Z_p = Z_S \parallel Z_L'$, plot Z_p on the impedance graph

plot Z_{CAP} on the same graph.

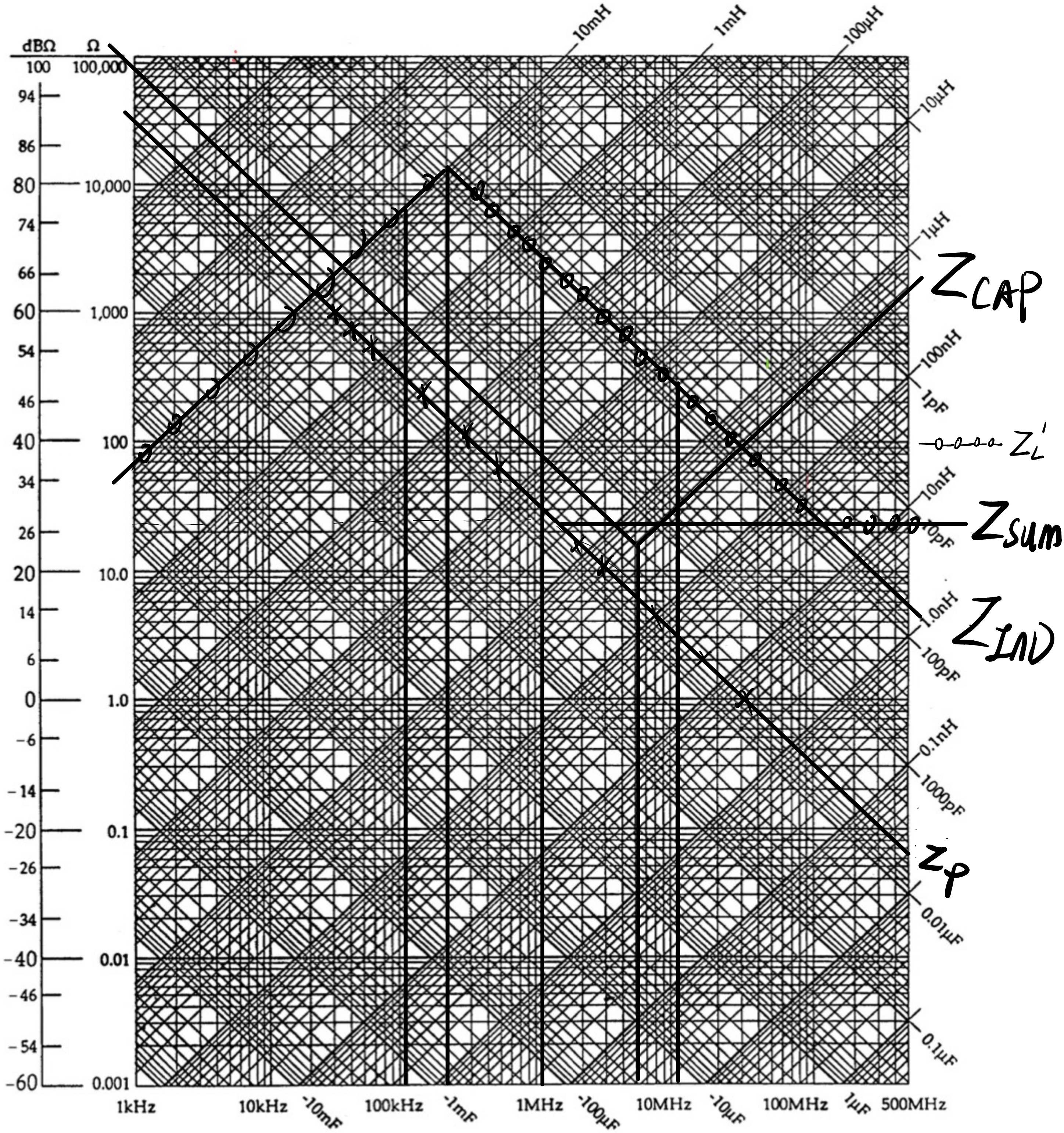
Attenuation occurs when $Z_{CAP} < Z_p$.

freq.	attenuation due to CAP.
100 KHz	0 dB
1MHz	0 dB
10 MHz	0dB

freq	A_{CAP}	A_{IND}	A_{total}
100kHz	0 dB	27 dB	27 dB
1MHz	0 dB	400dB	400dB
10MHz	0 dB	21dB	21dB

(c) According to (a) and (b), we know that the shunt capacitor C_Y (1000pF) is too small to provide any attenuations. All the attenuations are provided by the series inductor.

We can further choose the shunt capacitors $C_Y > \frac{1}{2}$ the capacitor of the noise sourse impedance



dBΩ
Ω
100
100,000
94
86
80
10,000
74
66
60
1,000
54
46
40
100
34
26
20
10.0
14
6
0
1.0
−6
−14
−20
0.1
−26
−34
−40
0.01
−46
−54
−60
0.001
1kHz
10kHz
100kHz
1MHz
10MHz
100MHz
500MHz
10mF
1mF
100μF
10μF
1μF
10mH
1mH
100μH
10μH
1μH
100nH
1pF
10nH
10pF
1.0nH
100pF
0.1nH
1000pF
0.01μF
0.1μF
Z_{CAP}
Z_L'
Z_{SUM}
Z_{IND}
Z_P

2015-2016 2.

2. Figure 1 shows a noisy circuit connected to a victim circuit. The noisy circuit can be modelled by a 2 MHz noise source and an equivalent source resistance of 1 kΩ. The victim circuit can be represented by a 10 kΩ resistance. A shunt capacitor is needed to attenuate the 2 MHz noise signal by at least 20 dB to ensure satisfactory operation of the victim circuit.

(a) Table 2 provides three readily available capacitors in the market for the filter design. Select the capacitor that meets the attenuation requirement. Justify your answer with the estimation of filter attenuation using the impedance graph provided. Please show your working on the impedance graph and attach it to your answer booklet.

(14 Marks)

(b) Based on the filter attenuation obtained from part (a), is larger capacitor value always a better choice for filter design? Justify your answer with reason.

(3 Marks)

(c) If the victim circuit's resistance is changed to 10 Ω, will you still expect at least 20 dB attenuation for the capacitor selected in part (a)? Justify your answer with explanation. No working on the impedance graph is needed.

(3 Marks)

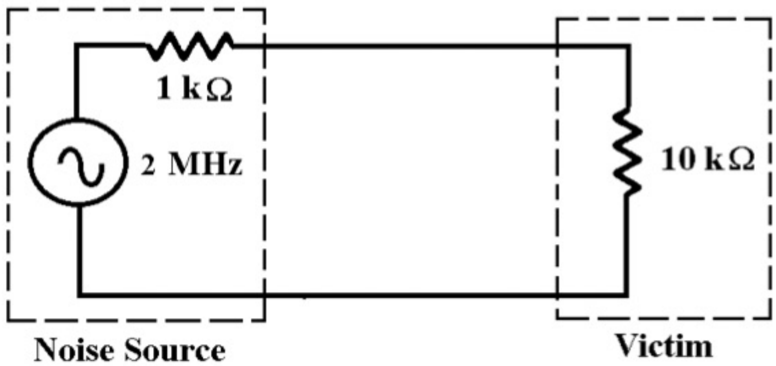


Figure 1

Table 2

Capacitor	Self-Resonant Frequency (SRF)
2 μF	10 kHz
0.2 μF	100 kHz
0.02μF	1 MHz

(a) $Z_S = 1k\Omega = 60\ dB\Omega$

$Z_L = 10k\Omega = 80\ dB\Omega$

$Z_P = Z_L // Z_S \approx 900\Omega \approx 59\ dB\Omega$, plot Z_P on the impedance graph.

plot all of the three capacitors on the same graph.

Attenuation occurs when $Z_{CAP} < Z_P$.

From the Impedance graph.

Capacitor	Attenuation @ 2MHz
$2\mu F$	0 dB
$0.2\mu F$	$59-44 = 15dB$
$0.02\mu F$	$59-24 = 35dB > 20dB$

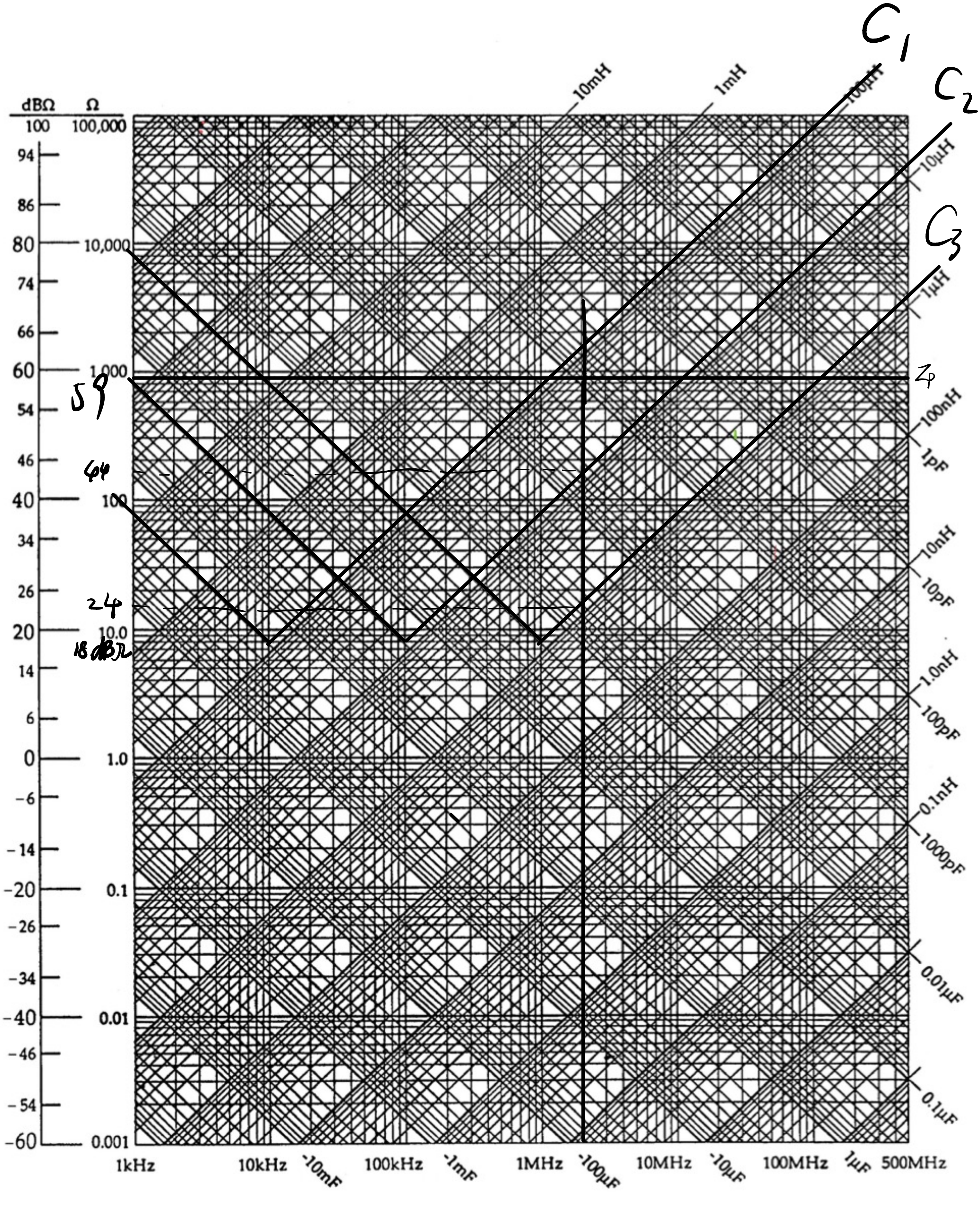
Hence, we select the capacitor with capacitance $0.02\mu F$.

(b) Large capacitor value doesn't always a better choice.

Like the result in part (a), $2\mu F$ capacitor provides 0dB attenuation at 2MHz, but $0.02\mu F$ capacitor can provide 35dB attenuation. Because $0.02\mu F$ capacitor has higher self-resonant frequency (1MHz), which promises this capacitor to produce attenuation at a wide range of frequency.

(c) If $Z_L = 10\Omega$, it means that $Z_P = 10\Omega = 20\ dB\Omega$.

All of these capacitors provided have minimum impedance at their SRF, which is approximately $18\ dB\Omega$, it is very close to Z_P, hence it's impossible to provide attenuation more than 2dB.



C1
C2
C3
dBΩ
Ω
100
100,000
94
86
80
10,000
74
66
60
1,000
59
54
46
44
40
100
34
26
24
20
10.0
18 dBΩ
14
6
0
1.0
-6
-14
-20
0.1
-26
-34
-40
0.01
-46
-54
-60
0.001
1kHz
10kHz
100kHz
1MHz
10MHz
100MHz
500MHz
10mF
1mF
100µF
10µF
1µF
10mH
1mH
100µH
10µH
1µH
Zp
100nH
1pF
10nH
10pF
1.0nH
100pF
0.1nH
1000pF
0.01µF
0.1µF