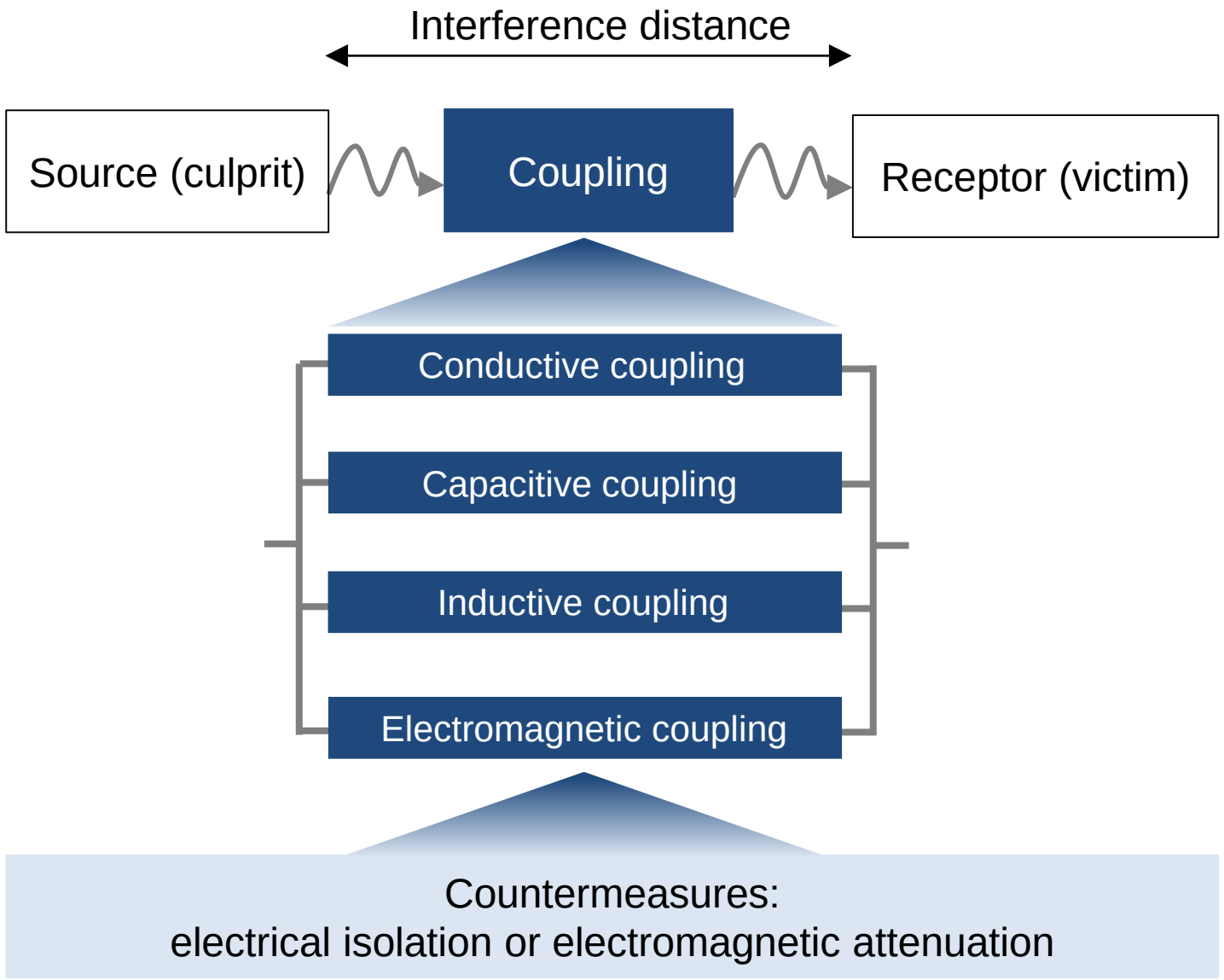
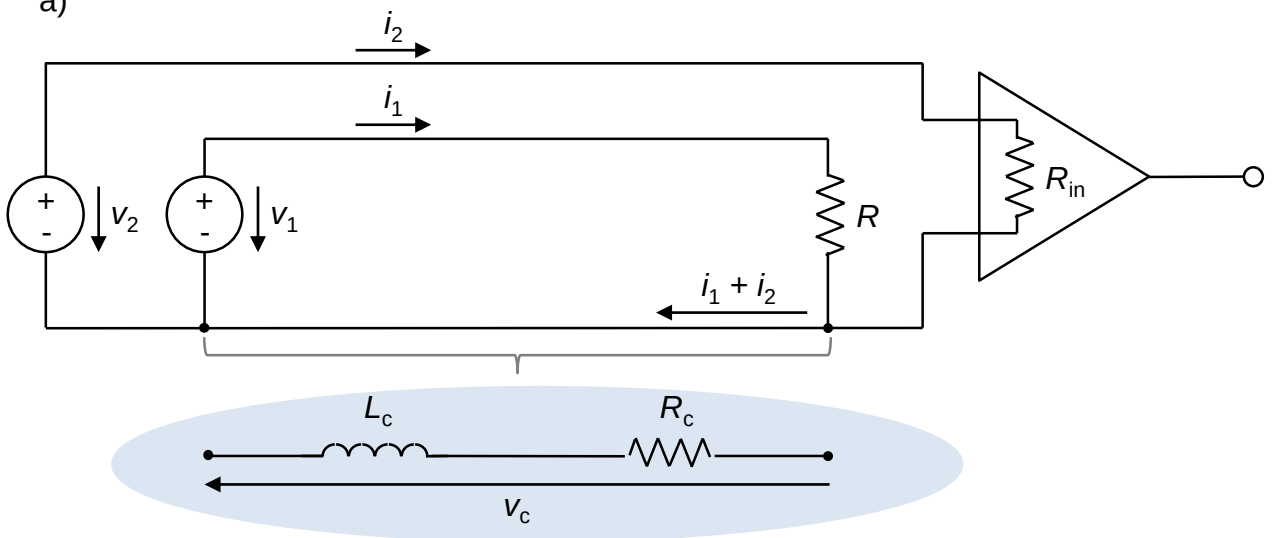
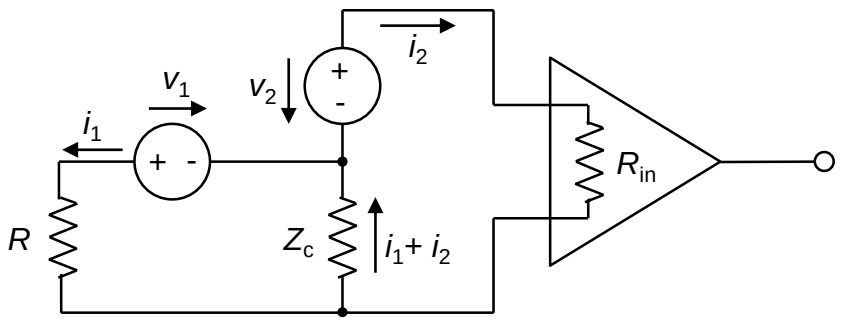
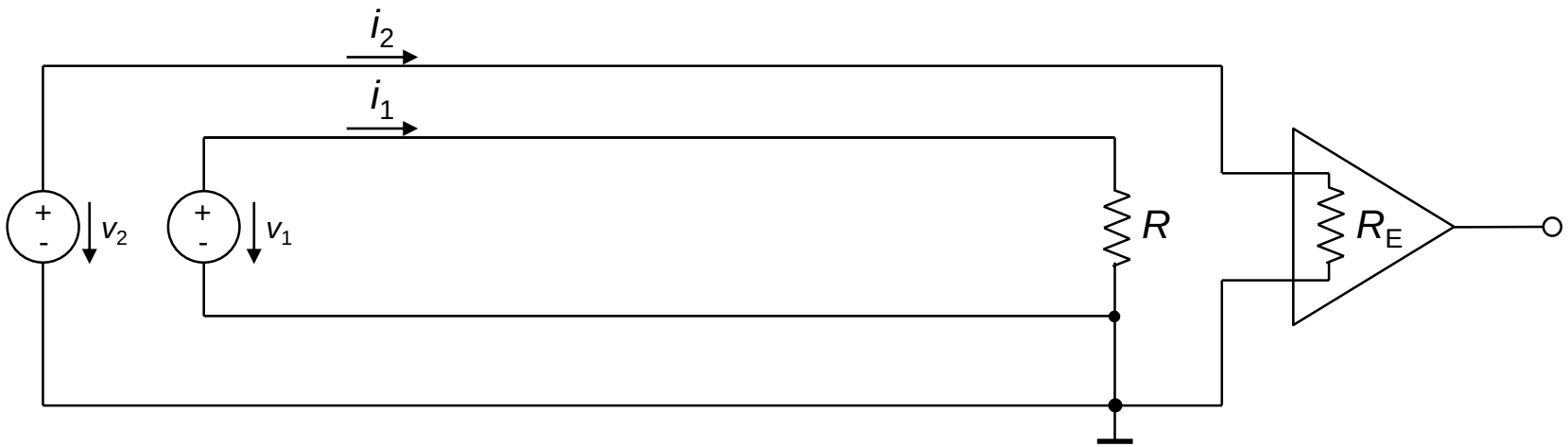


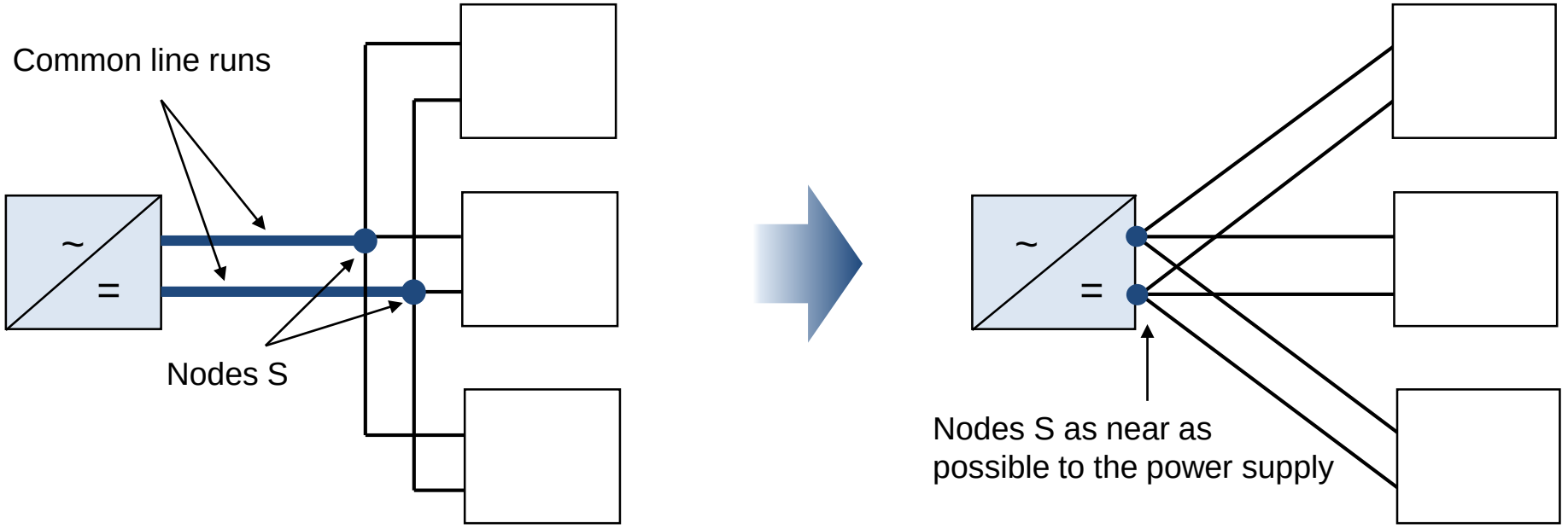
a)



b)



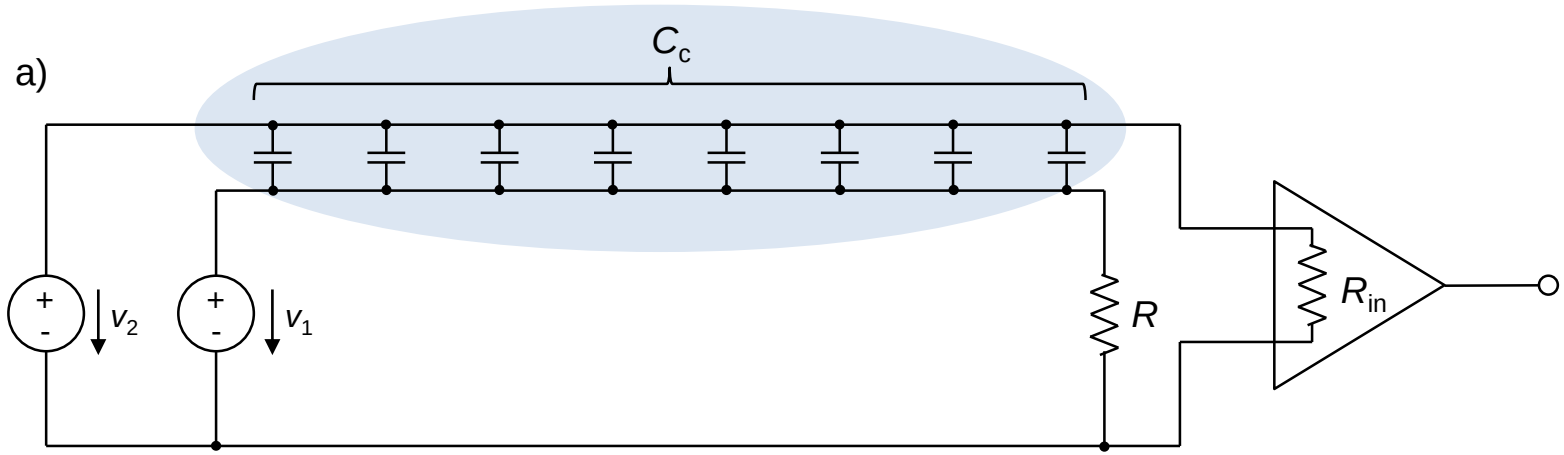

i_2
i_1
+
-
v_2
+
-
v_1
R
R_E


Common line runs
~
=
Nodes S
Nodes S as near as
possible to the power supply

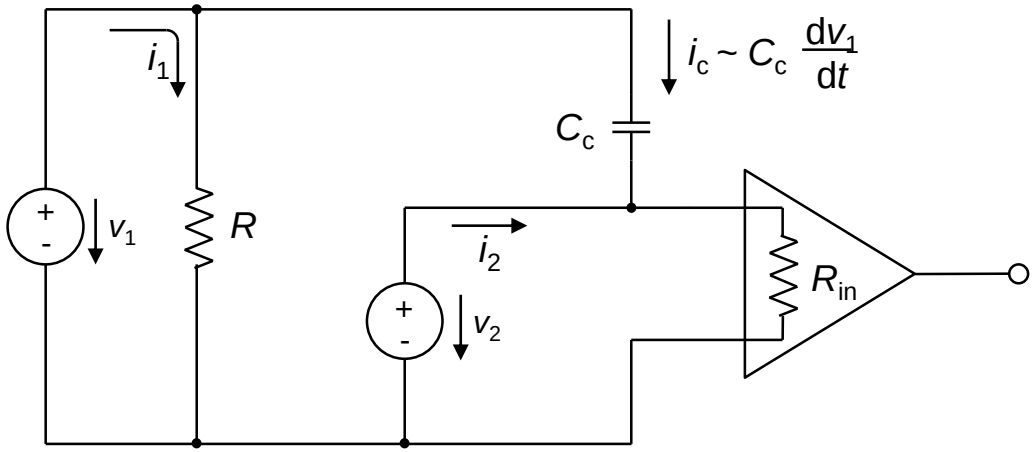
bad

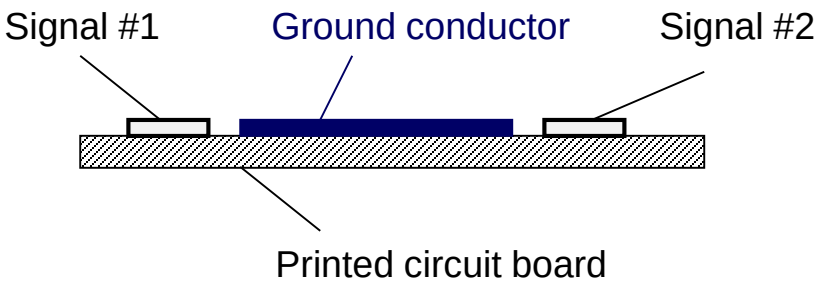
good

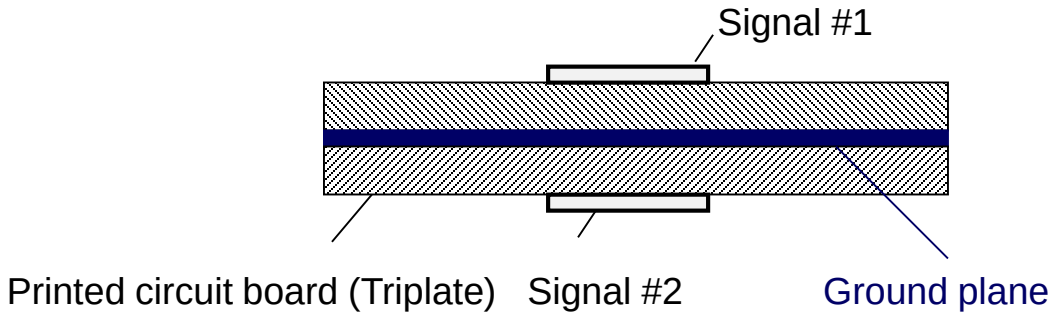
a)

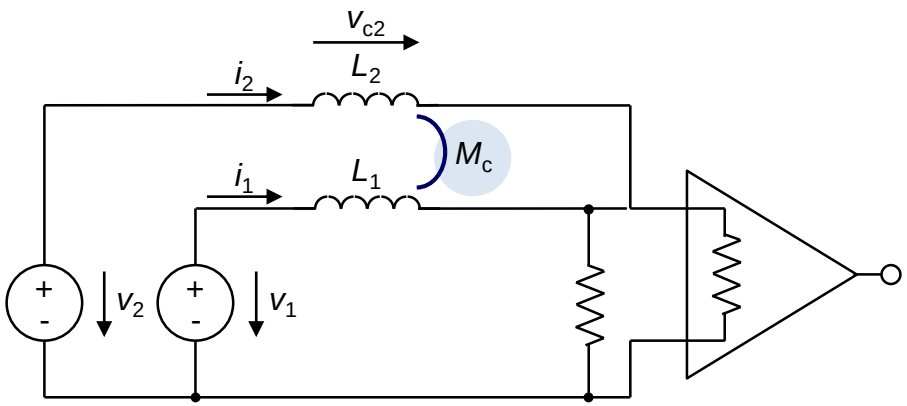


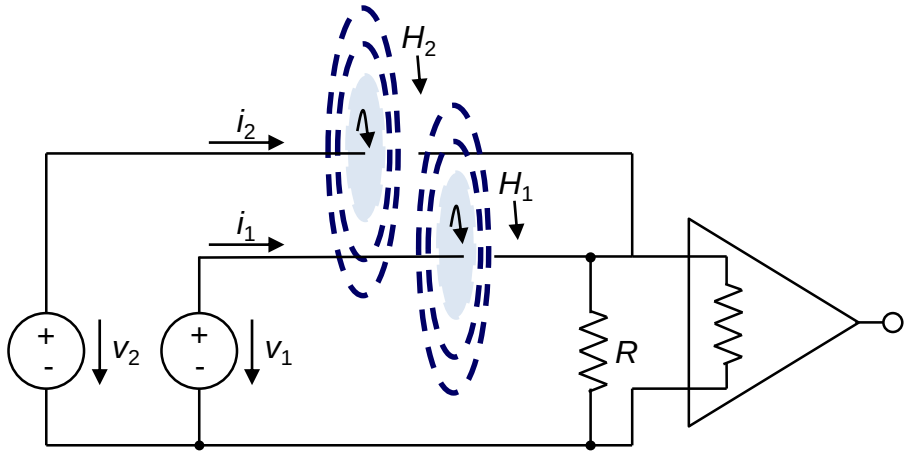
b)

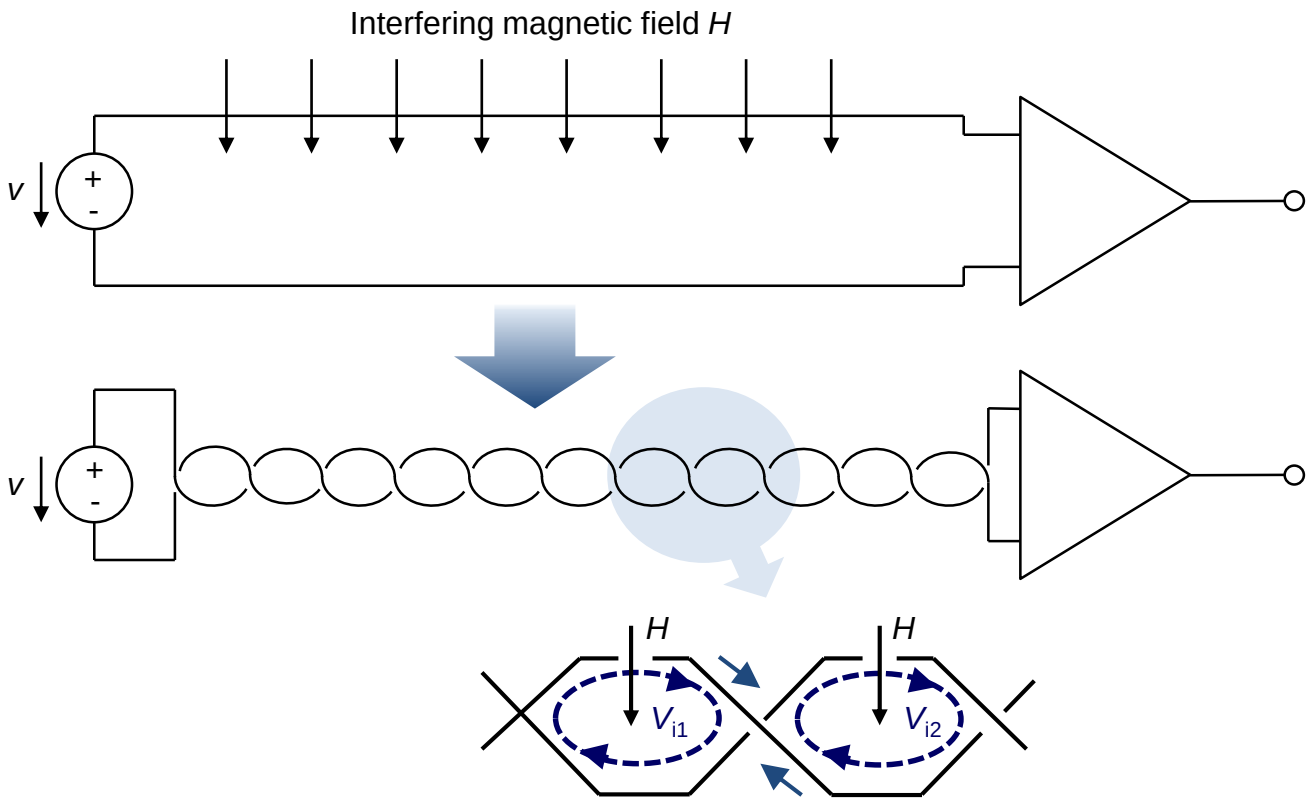


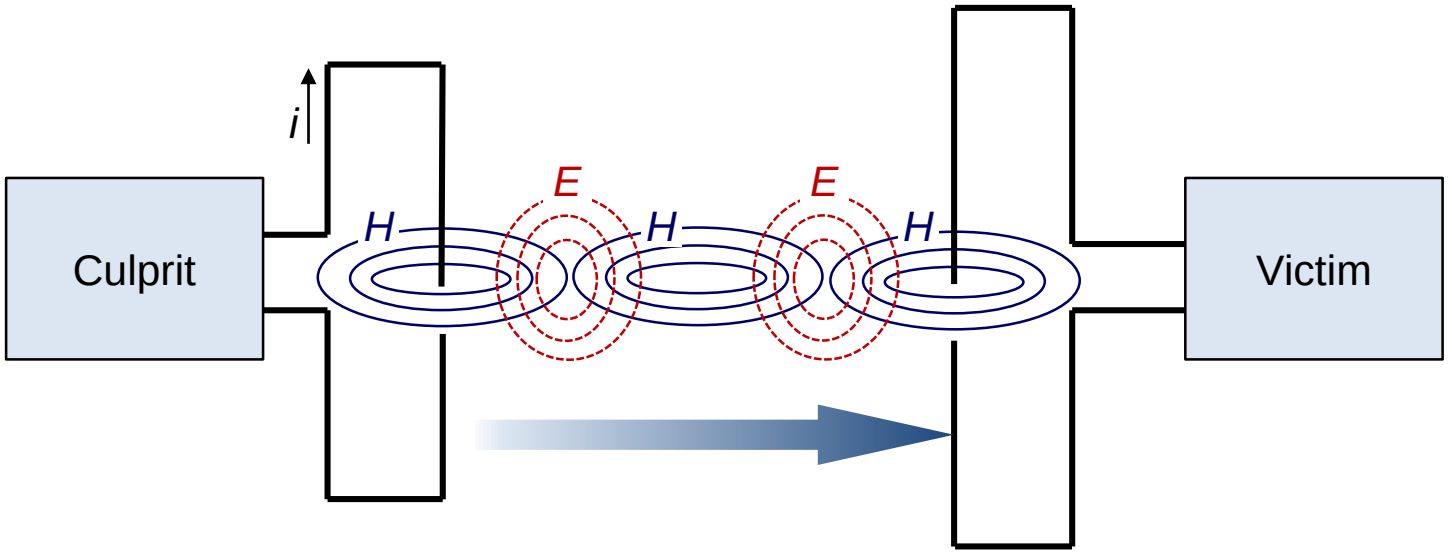

Signal #1
Ground conductor
Signal #2
Printed circuit board

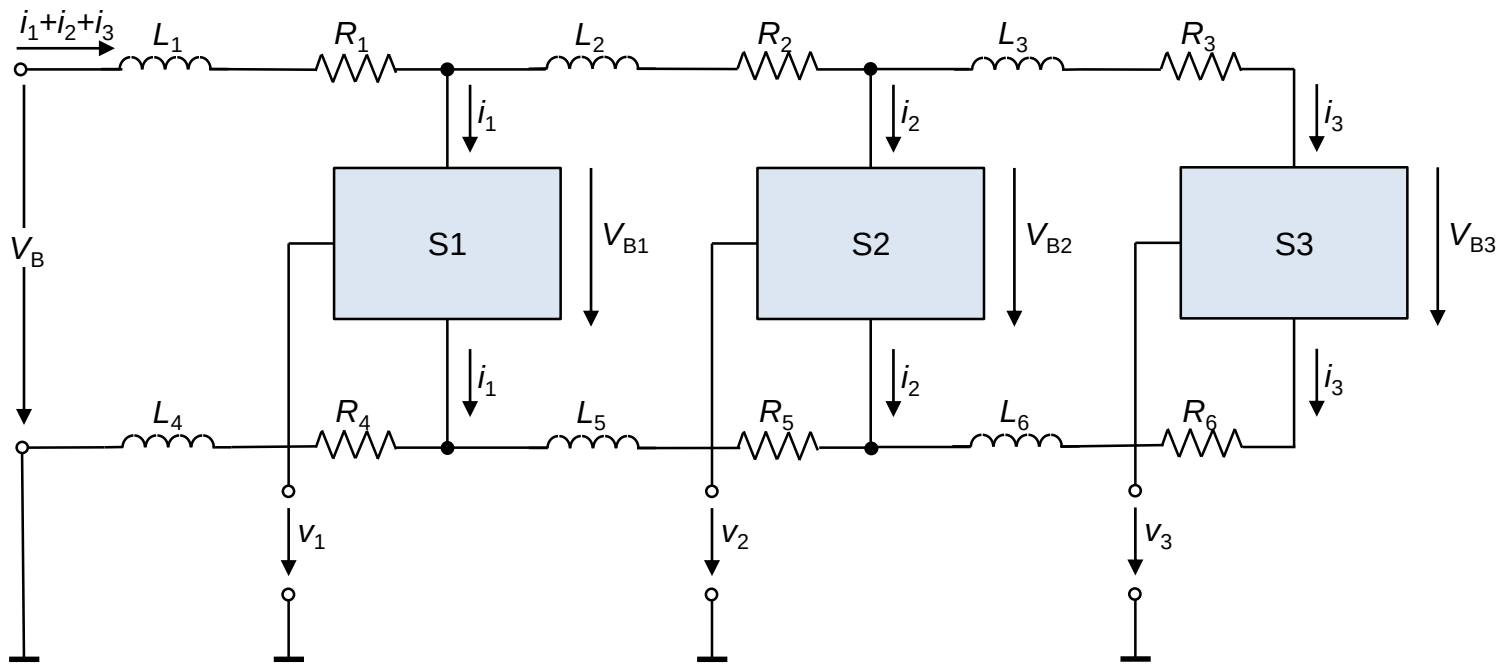

Signal #1
Printed circuit board (Triplate)
Signal #2
Ground plane

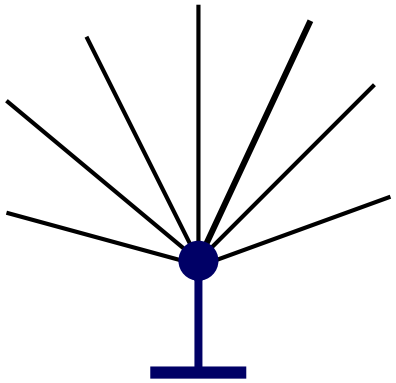

v_{c2}
i_2
L_2
M_c
i_1
L_1
+
-
v_2
+
-
v_1


H_2
i_2
H_1
i_1
+
-
v_2
+
-
v_1
R

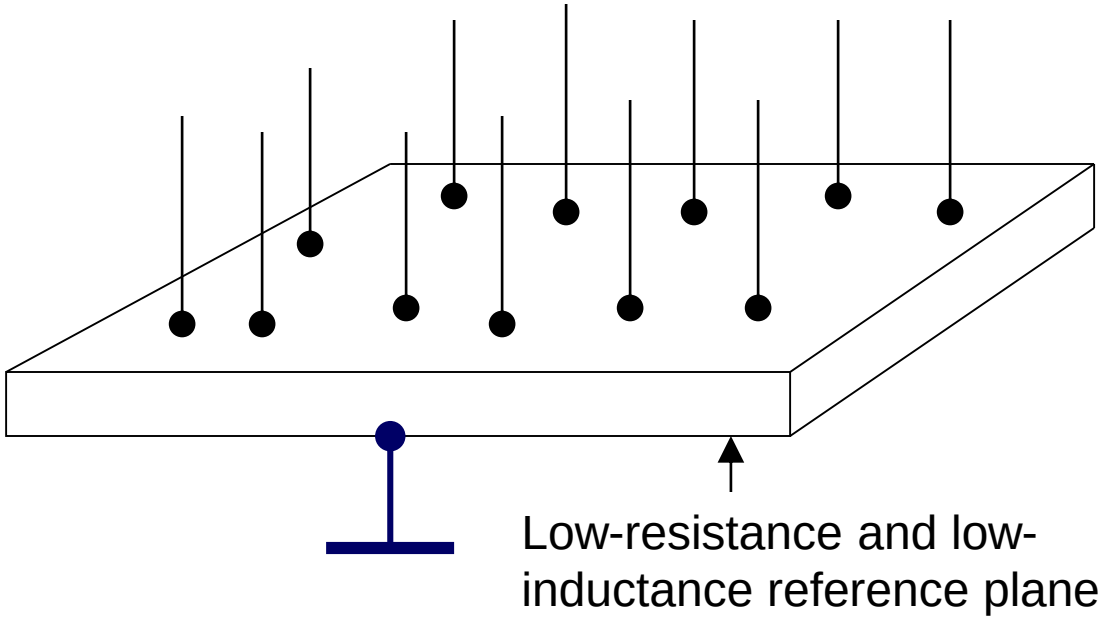

Interfering magnetic field H
v
+
-
v
+
-
H
H
Vi1
Vi2


i
E
E
H
H
H
Culprit
Victim

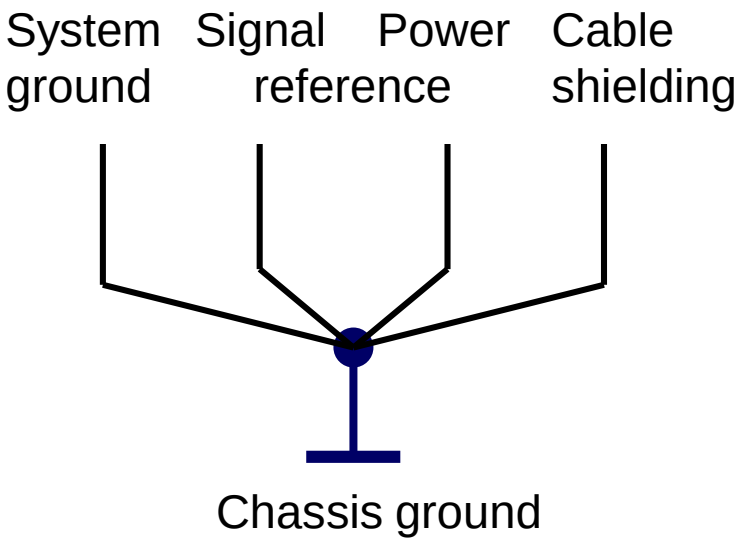

$i_1+i_2+i_3$
L_1
R_1
L_2
R_2
L_3
R_3
i_1
i_2
i_3
S1
S2
S3
V_B
V_{B1}
V_{B2}
V_{B3}
i_1
i_2
i_3
L_4
R_4
L_5
R_5
L_6
R_6
v_1
v_2
v_3



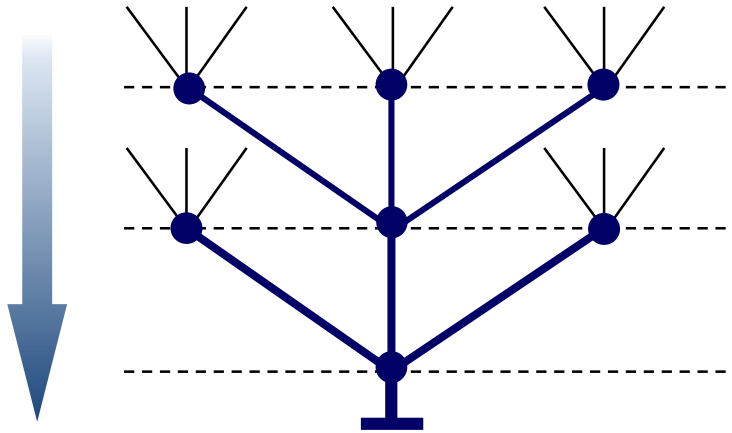
Single-point reference, single point ground



Reference plane, ground plane



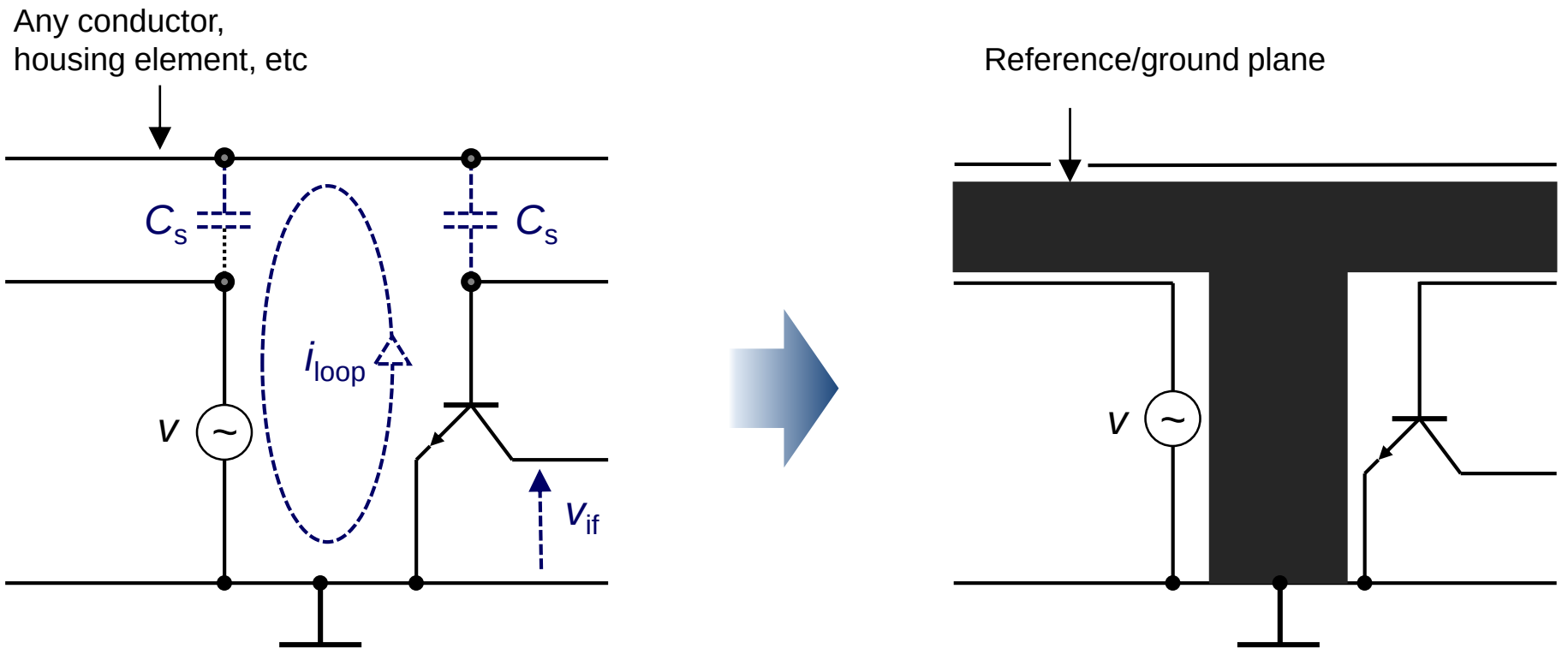
Increasing wire cross-section

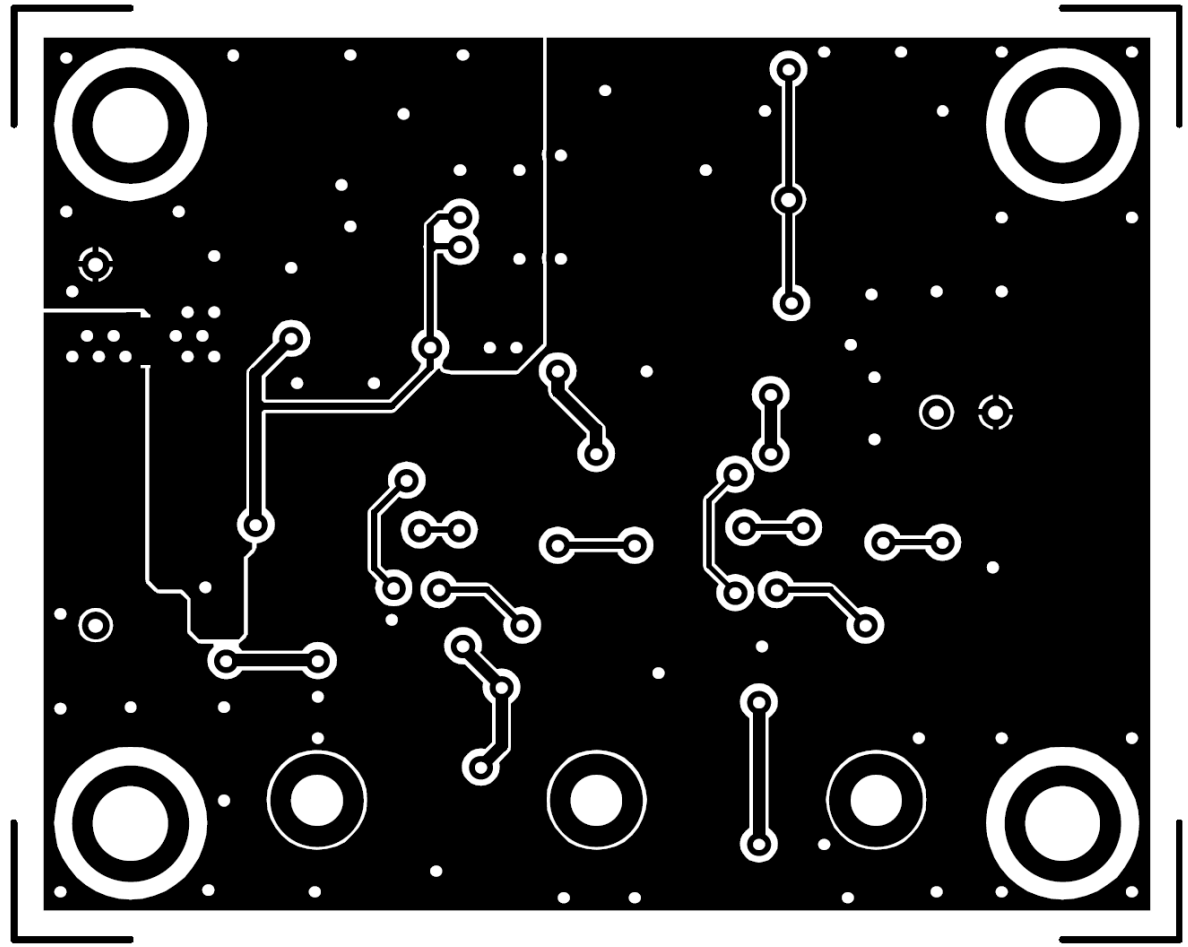


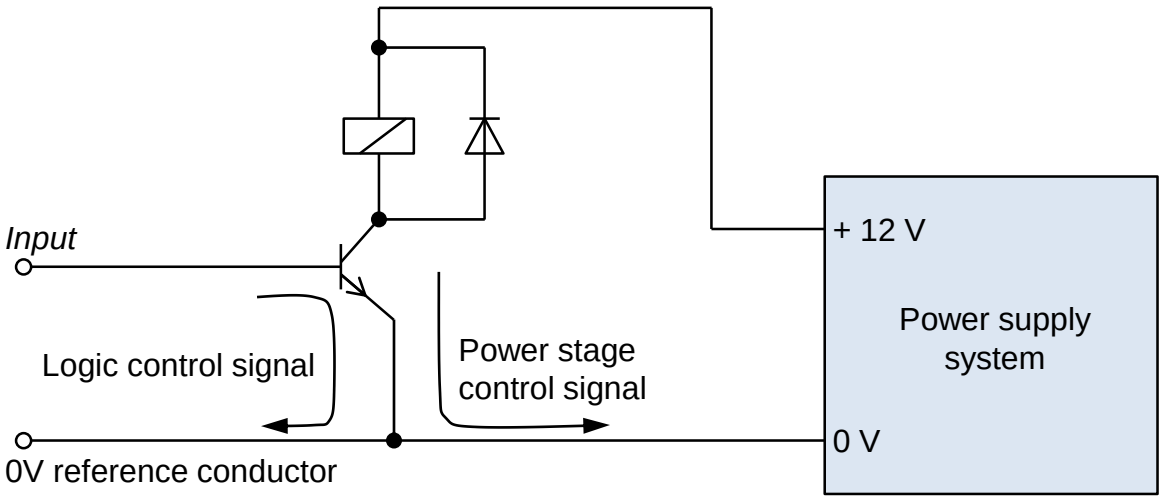
IC, MCM, PCB grounding scheme

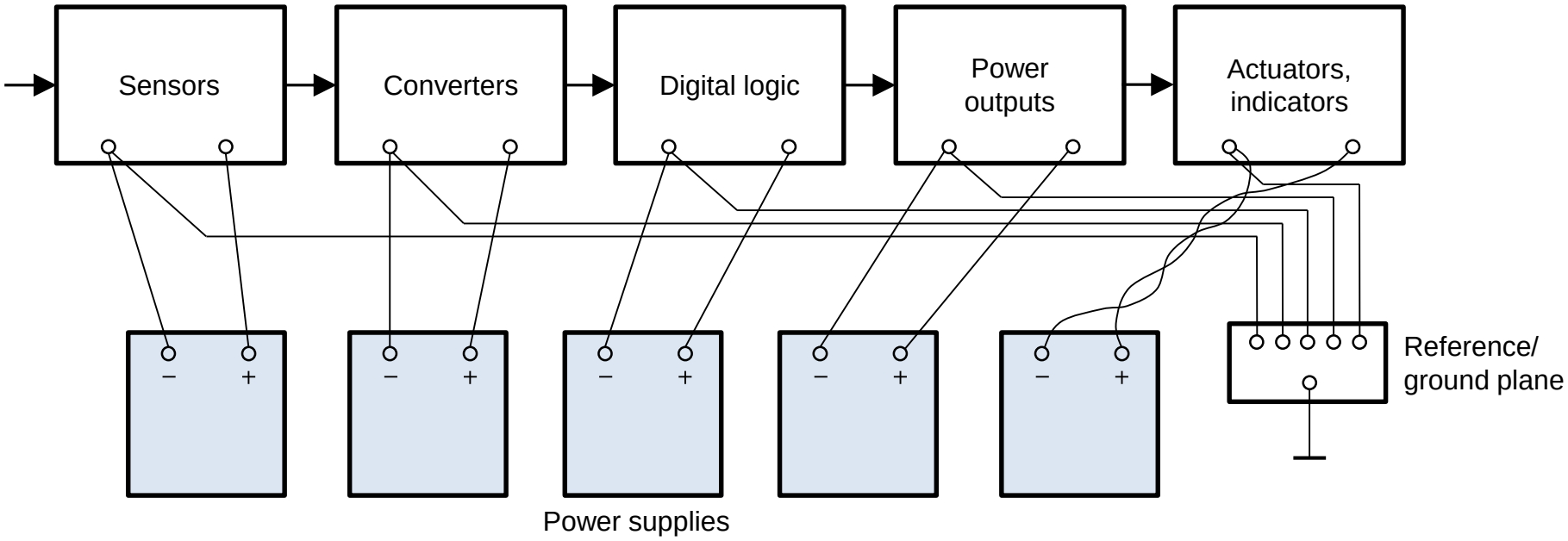
Module grounding scheme

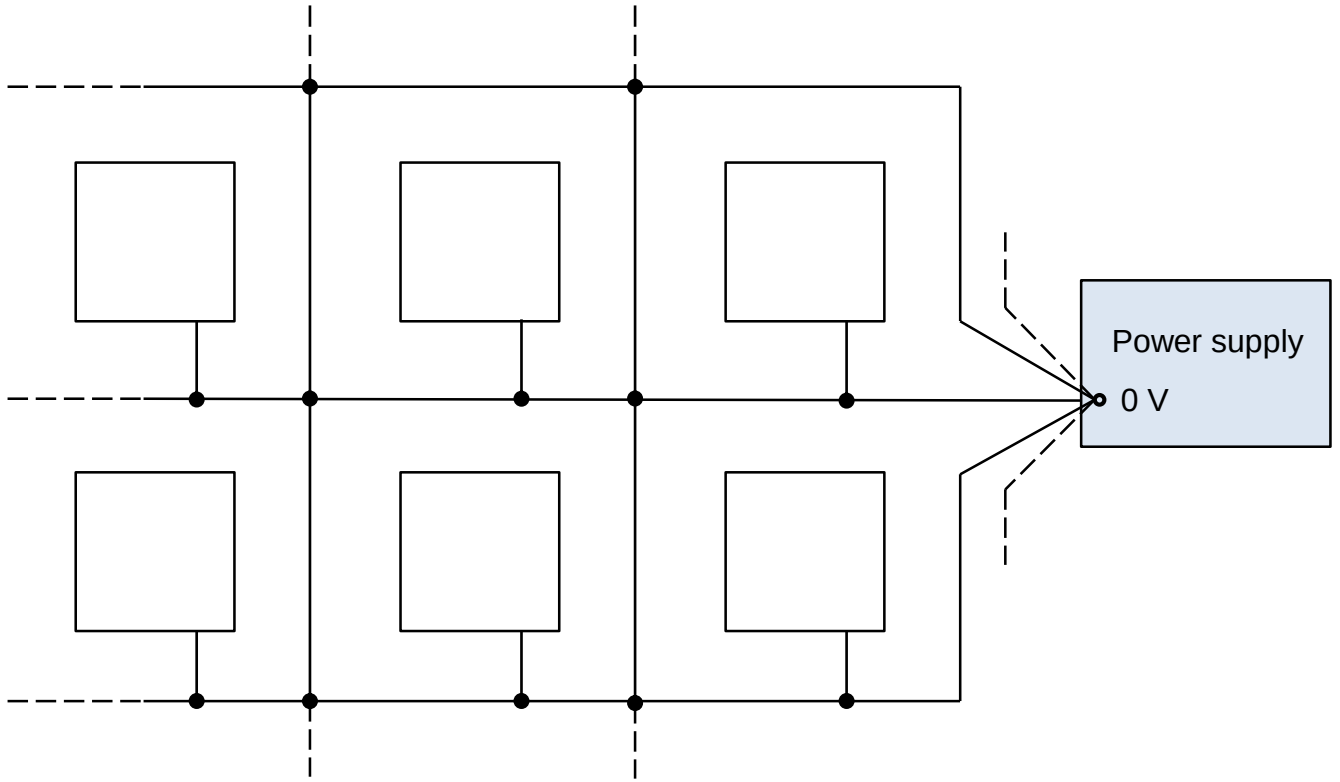
System grounding scheme

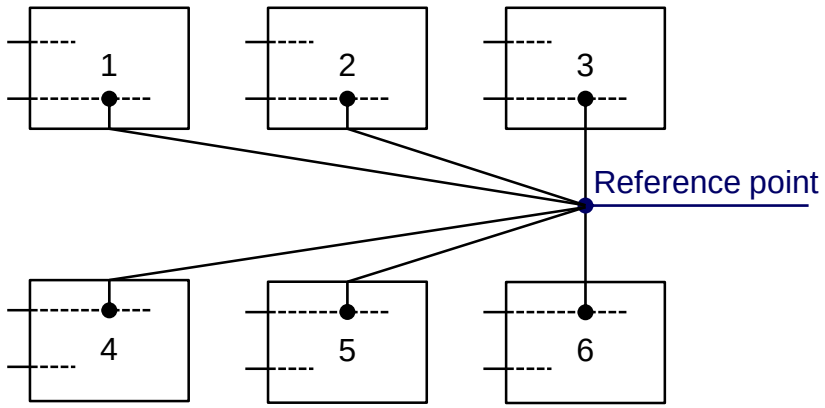

Any conductor,
housing element, etc
C_s
C_s
i_{loop}
v
v_{if}
Reference/ground plane
v

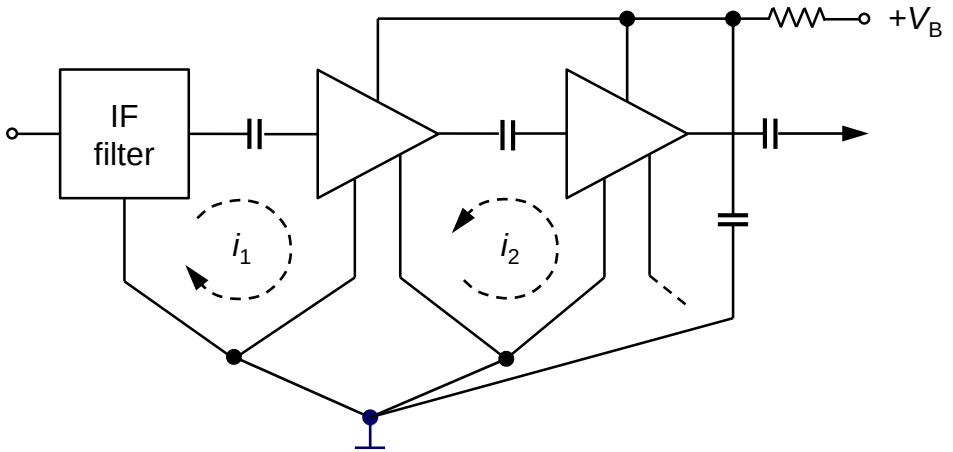


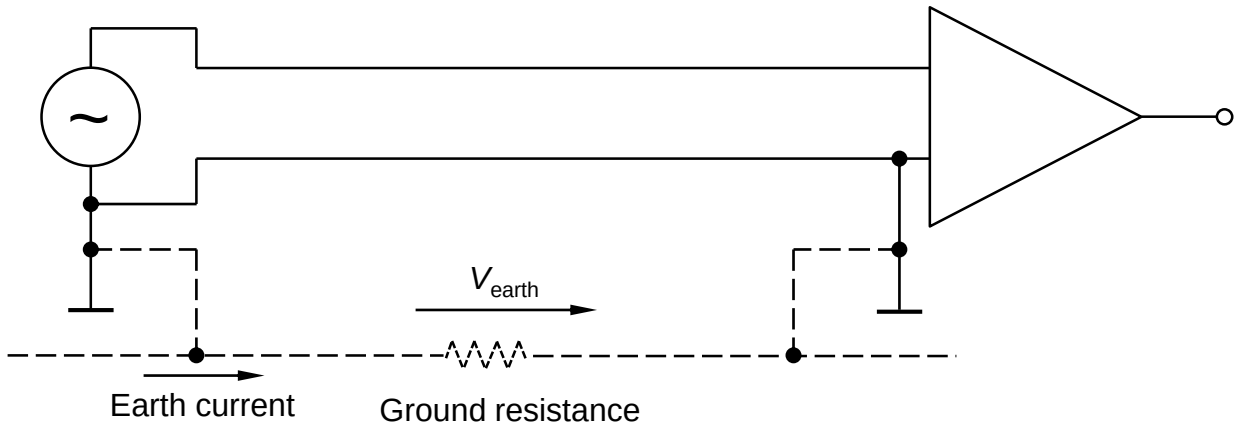

Input
Logic control signal
Power stage
control signal
0V reference conductor
+ 12 V
Power supply
system
0 V


Sensors
Converters
Digital logic
Power outputs
Actuators, indicators
Reference/ ground plane
Power supplies

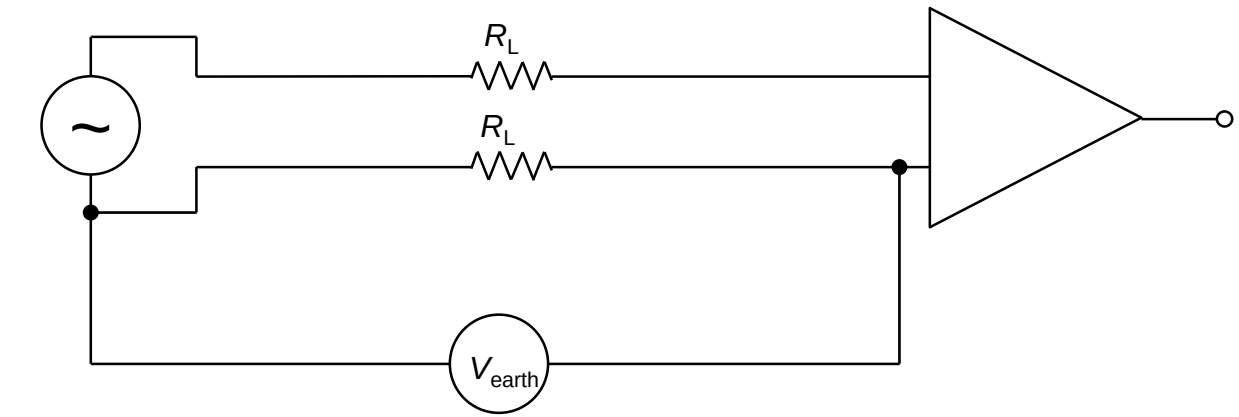

Power supply
0 V

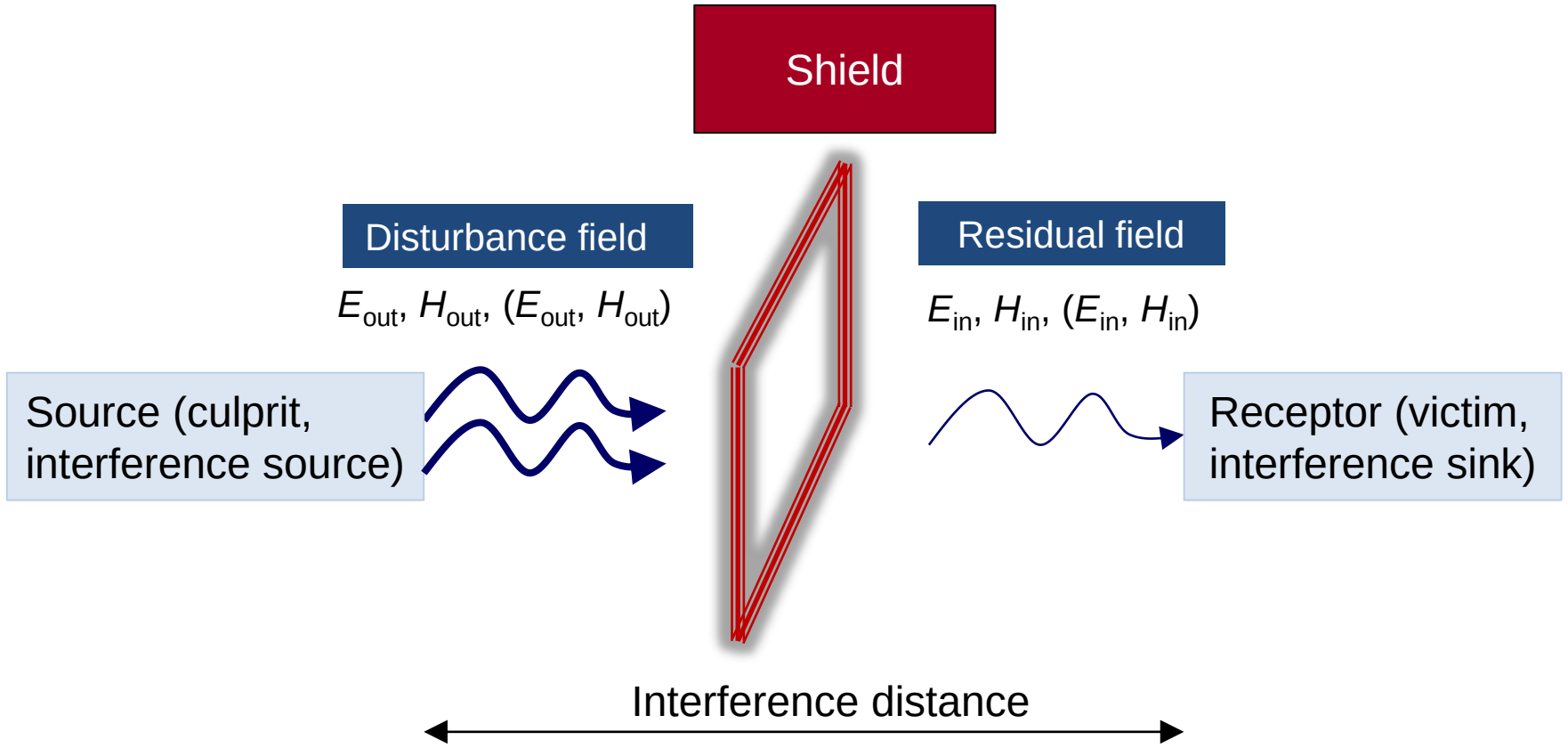

1
2
3
Reference point
4
5
6

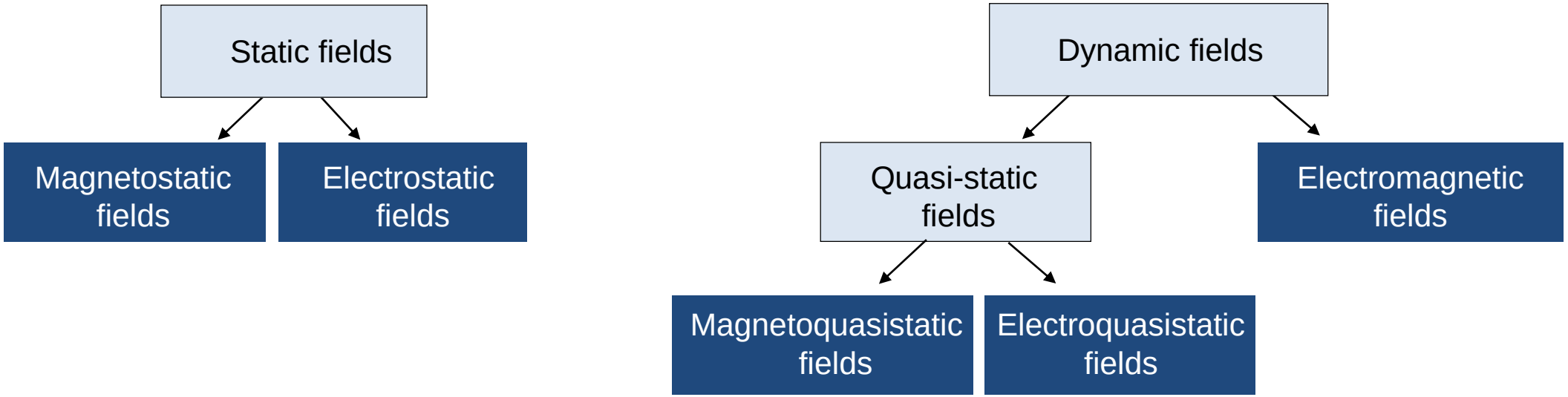

IF
filter
i_1
i_2
$+V_B$

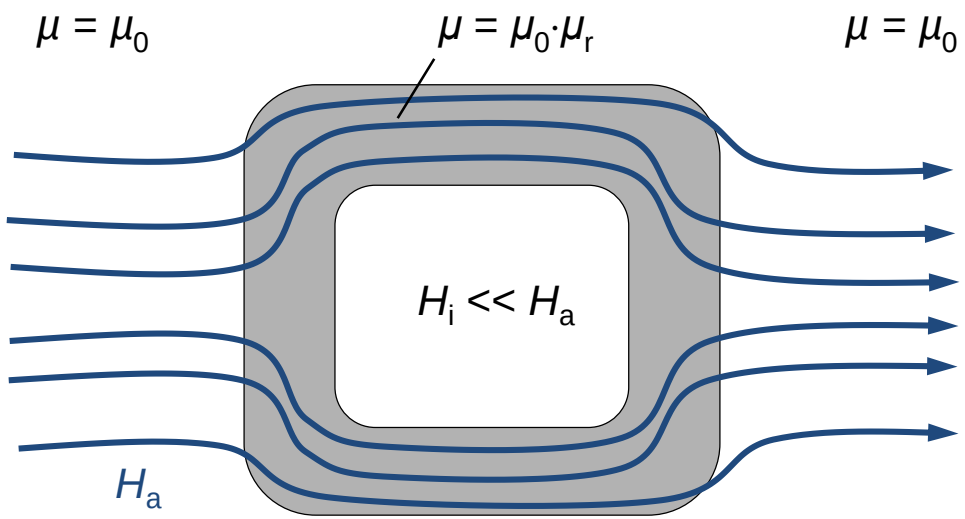


Equivalent circuit




Shield
Disturbance field
E_{out}, H_{out}, (E_{out}, H_{out})
Residual field
E_{in}, H_{in}, (E_{in}, H_{in})
Source (culprit, interference source)
Receptor (victim, interference sink)
Interference distance

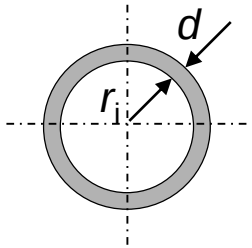

Static fields
Magnetostatic fields
Electrostatic fields
Dynamic fields
Quasi-static fields
Electromagnetic fields
Magnetoquasistatic fields
Electroquasistatic fields


$\mu = \mu_0$
$\mu = \mu_0 \cdot \mu_r$
$\mu = \mu_0$
$H_i << H_a$
H_a

Material	Superalloy	Mu metal	Permalloy	Nickel-iron	Carbon steel	Nickel
μ_r	100,000	25,000	4,500	1,000	200	100

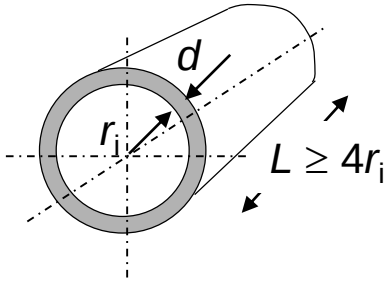
Shielding effectivness SE_H (in dB)

Sphere



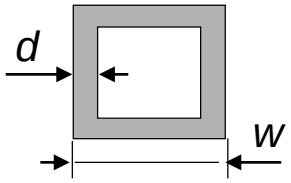
$$SE_H = 20 \cdot \log_{10}(1 + \frac{2}{3}\mu_r \cdot \frac{d}{r_i})$$

Cylinder

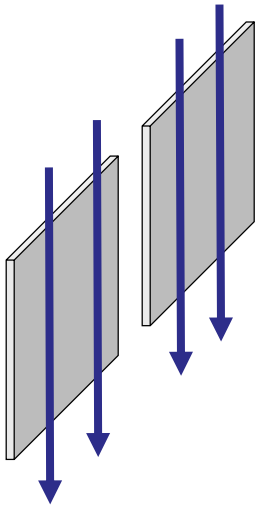


$$SE_H = 20 \cdot \log_{10}(1 + \frac{1}{2}\mu_r \cdot \frac{d}{r_i})$$

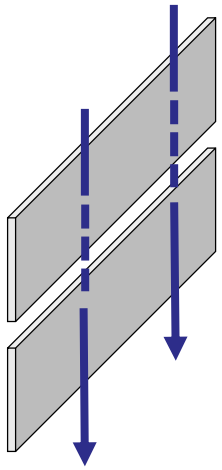
Cube (approximation)



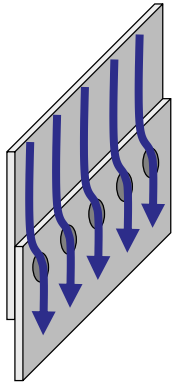
$$SE_H \approx 20 \cdot \log_{10}(1 + \frac{4}{5}\mu_r \cdot \frac{d}{w})$$



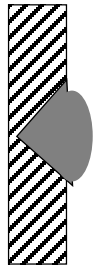
Good



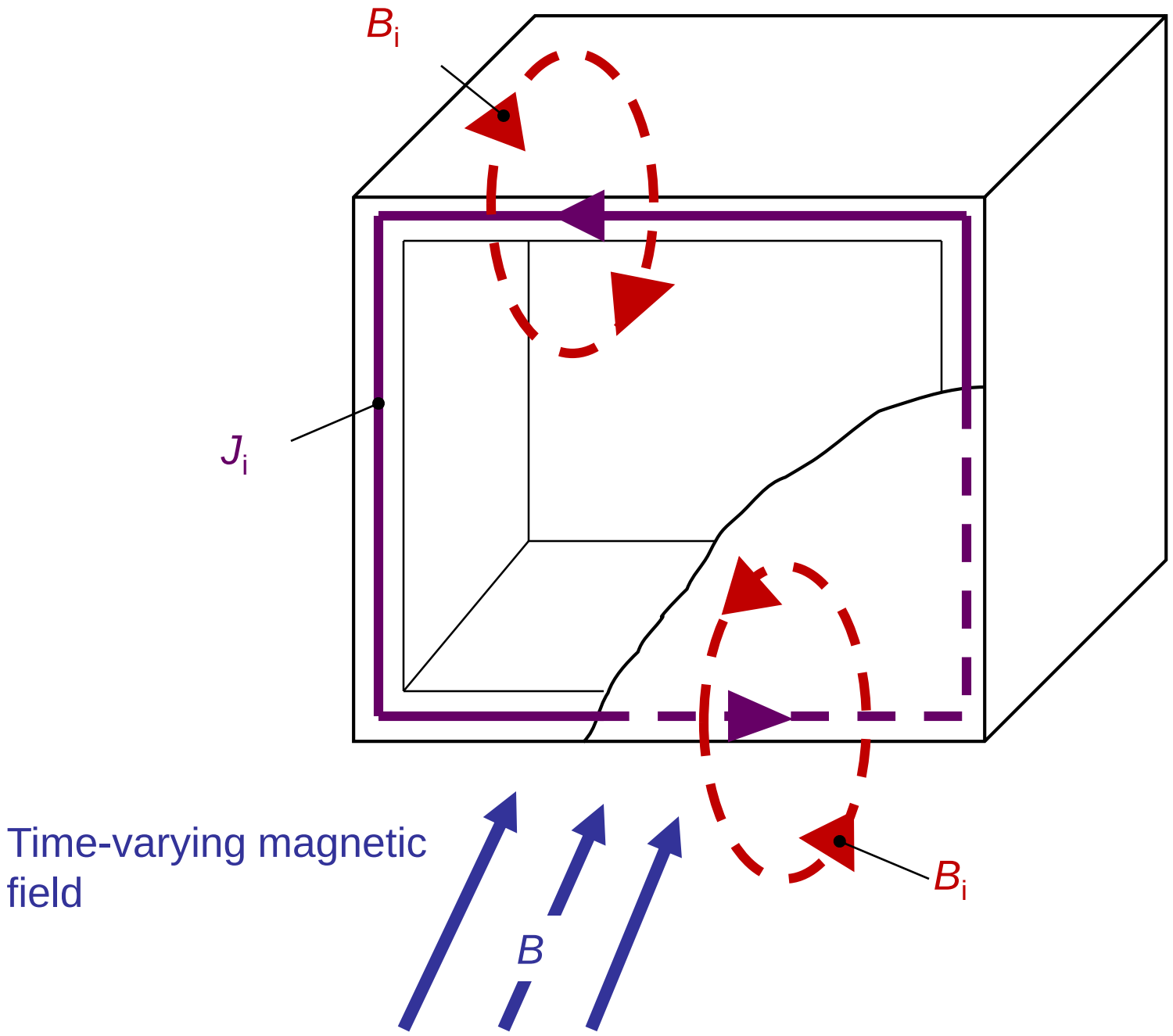
Bad



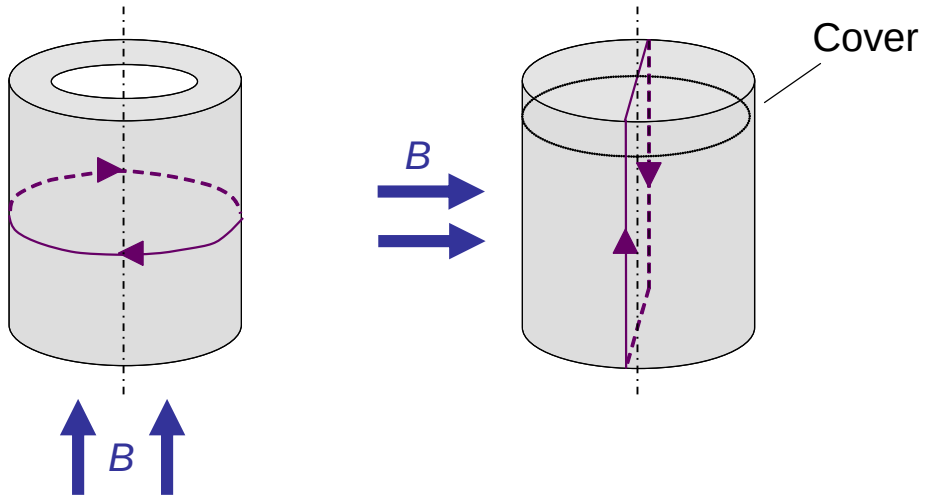
Spot welding with
low weld pitch

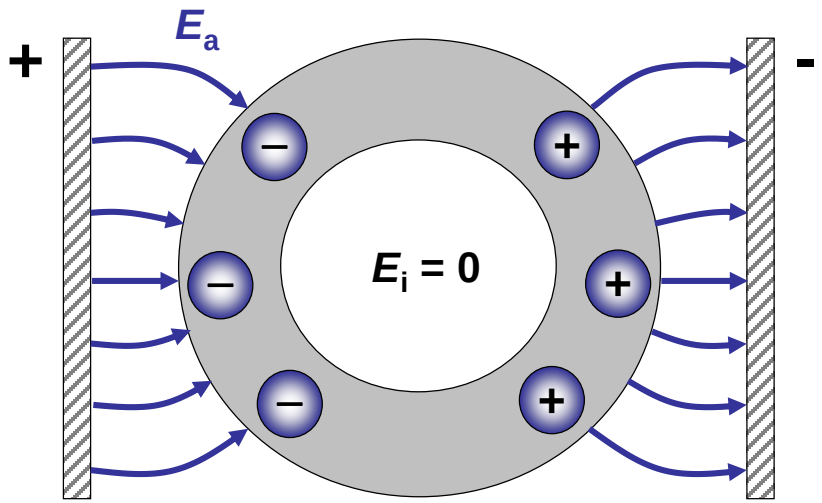


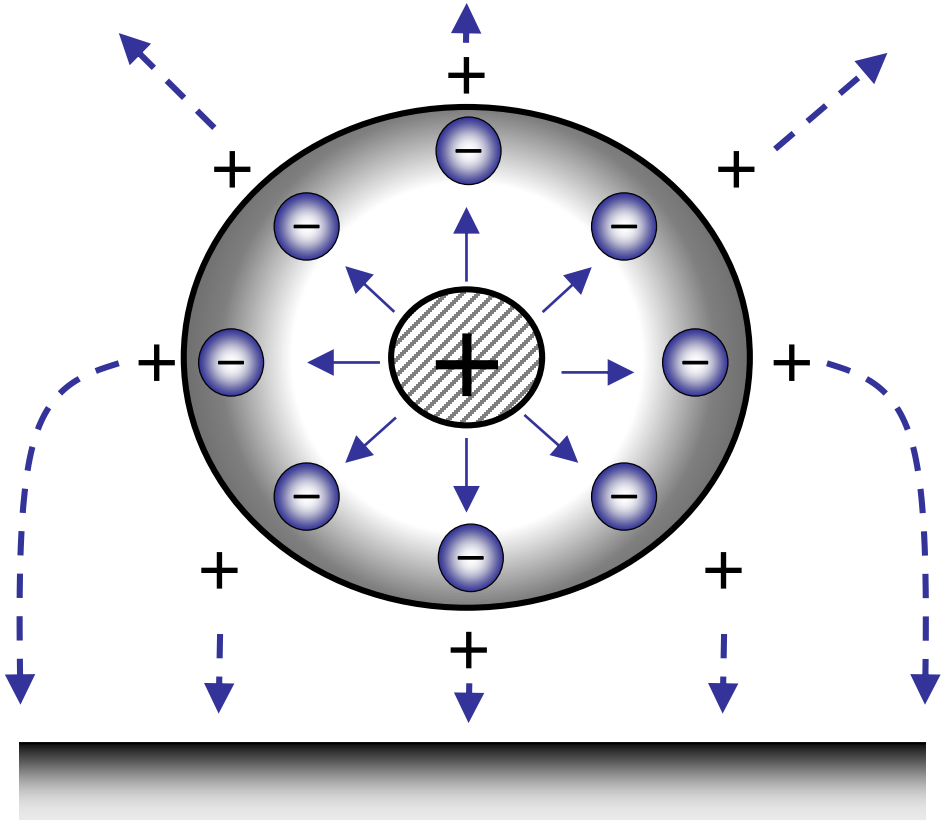
Adapt weld
(do not solder)

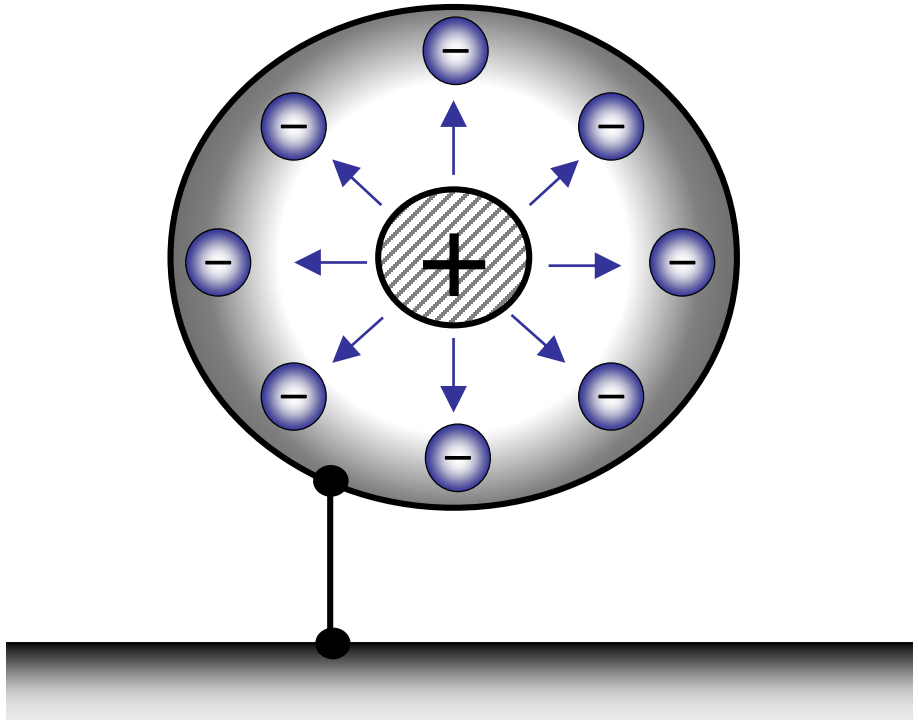

B_i
J_i
B_i
B
Time-varying magnetic field

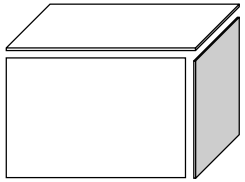
Material / Frequency	δ in mm				
	50 Hz	800 Hz	1 MHz	100 MHz	10 GHz
Copper	9.6	2.4	0.067	$6.7 \cdot 10^{-3}$	$6.7 \cdot 10^{-4}$
Aluminum	13.3	3.3	0.94	$9.4 \cdot 10^{-3}$	$9.4 \cdot 10^{-4}$
Iron ($\mu_r = 300$)	1.5	0.38	0.011	$1.1 \cdot 10^{-3}$	$1.1 \cdot 10^{-4}$
Mu-metal ($\mu_r = 25\,000$)	0.333	0.084	$2.36 \cdot 10^{-3}$	$2.36 \cdot 10^{-3}$	$2.36 \cdot 10^{-5}$


B
B
Cover

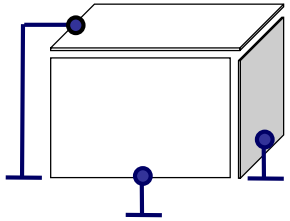

+
E_a
-
$E_i = 0$



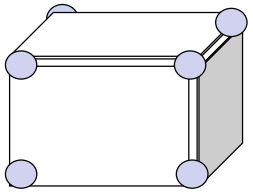




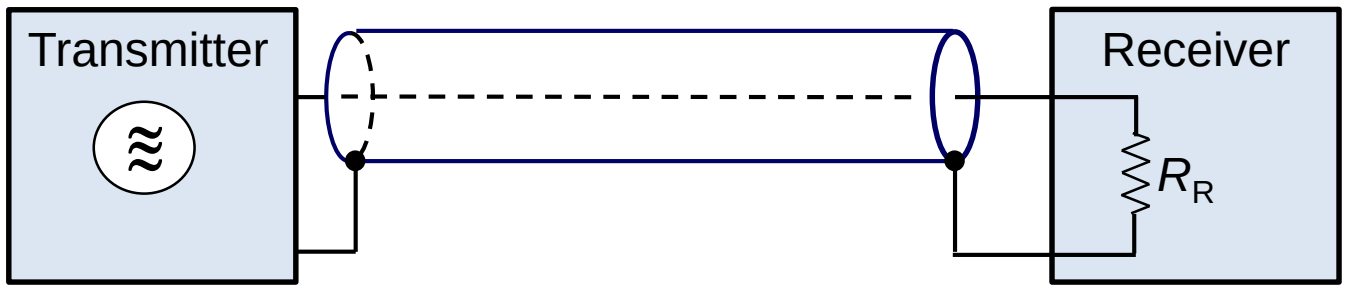
Ineffective

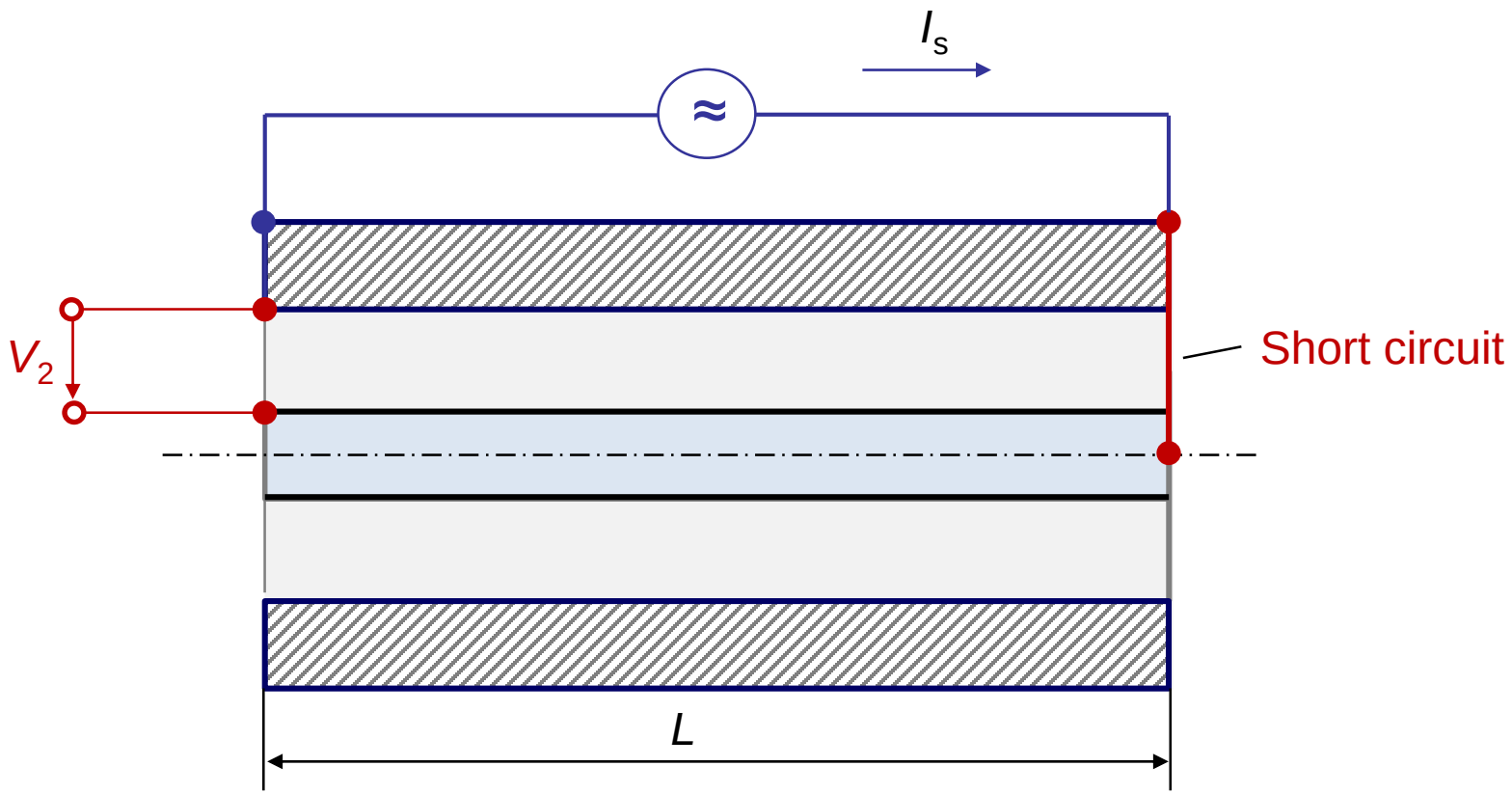


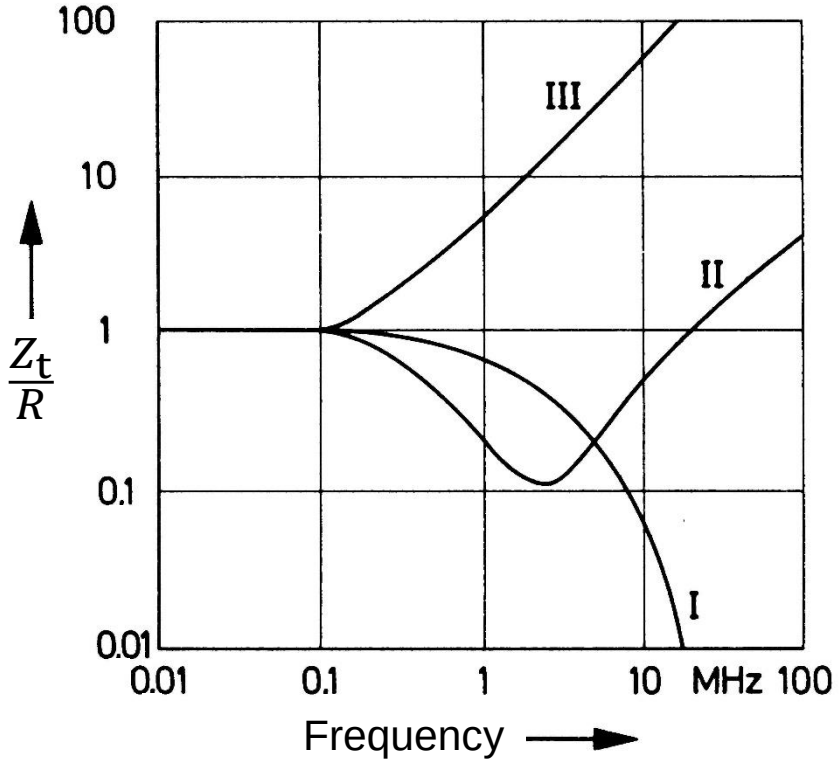
Grounding

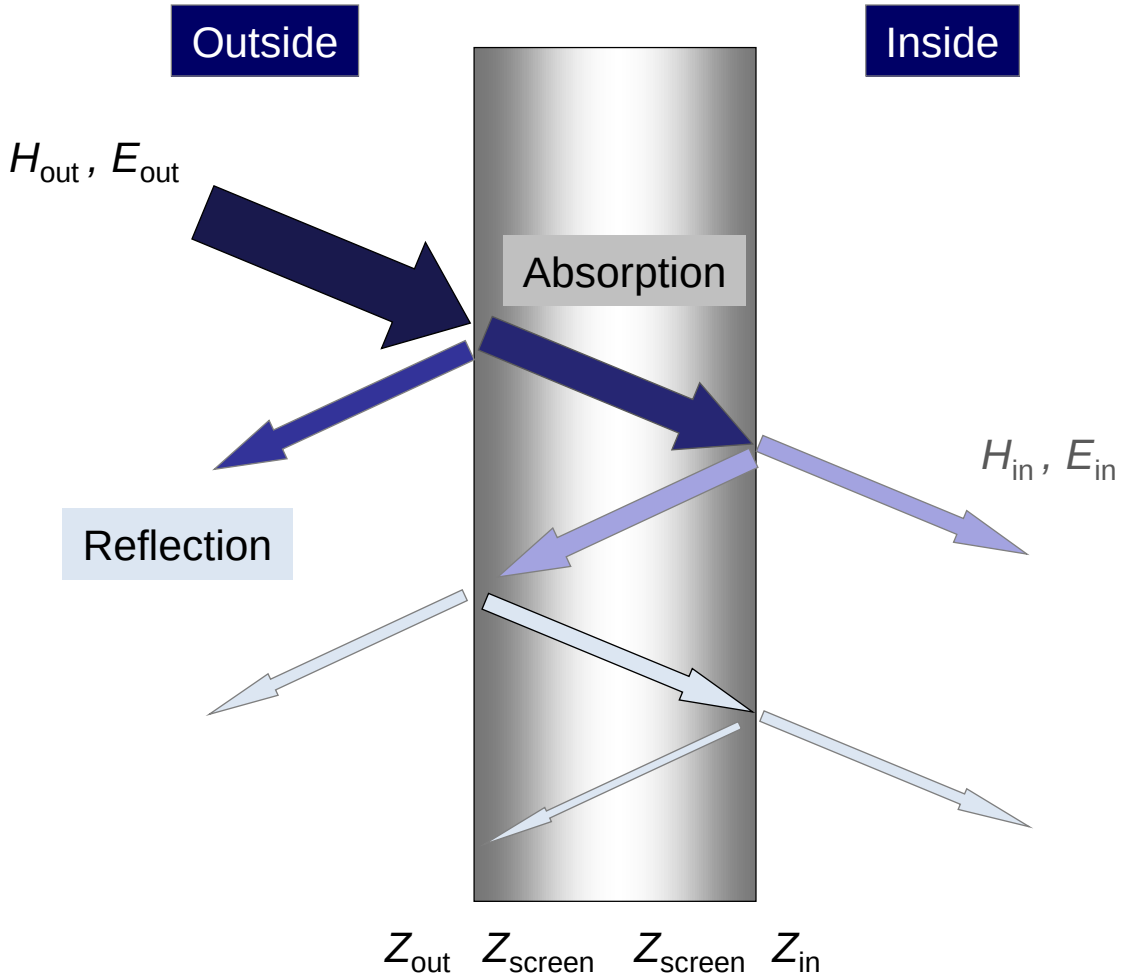


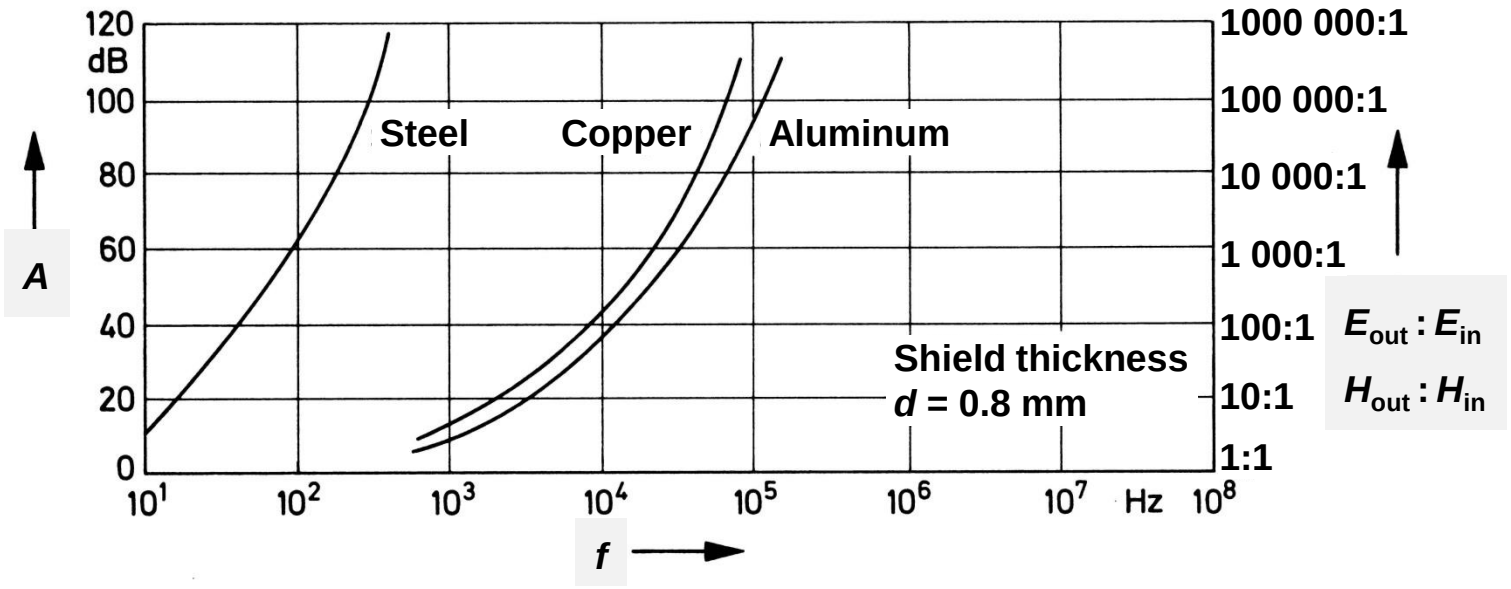
Connections for electrical potential equalization

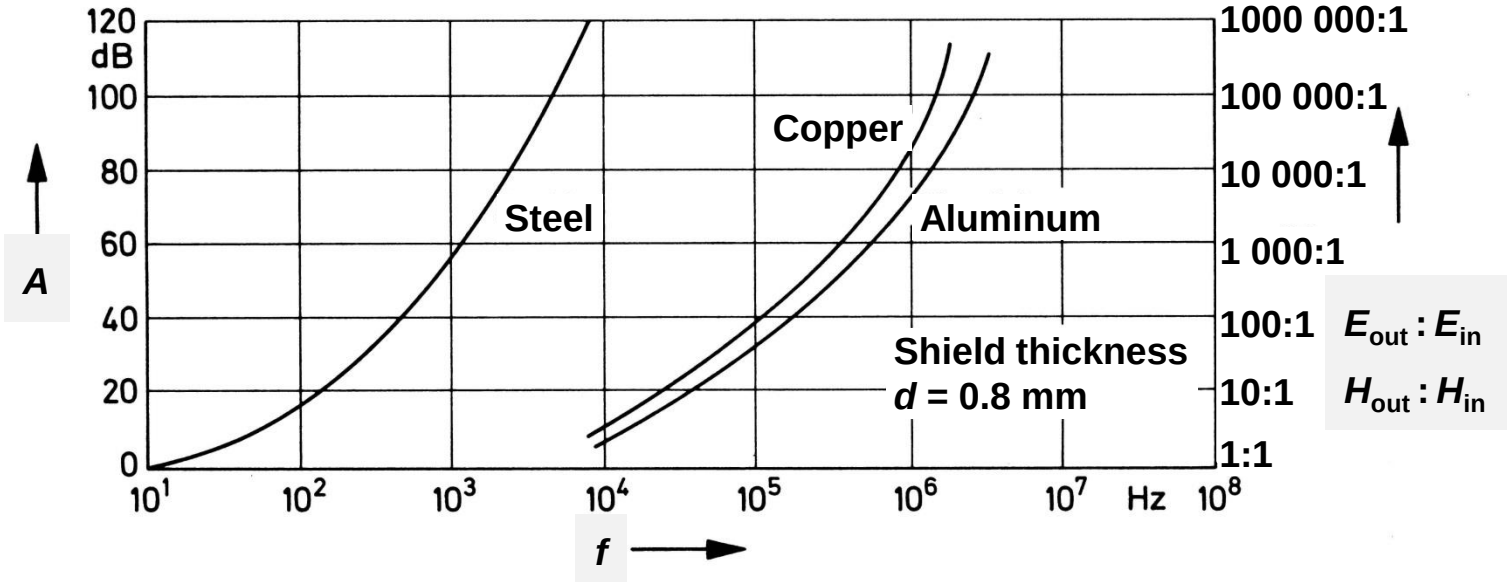

Transmitter
Receiver
R_R

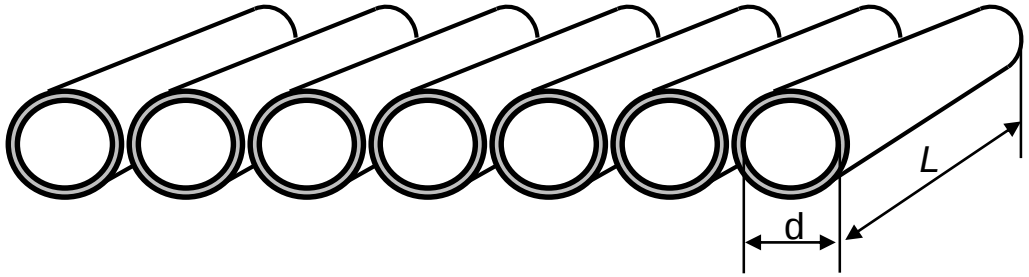

I_s
≈
V_2
Short circuit
L

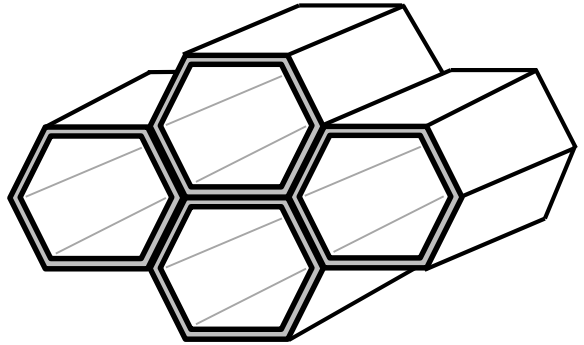

100
10
1
0.1
0.01
$\frac{Z_t}{R}$
III
II
I
0.01
0.1
1
10
MHz
100
Frequency

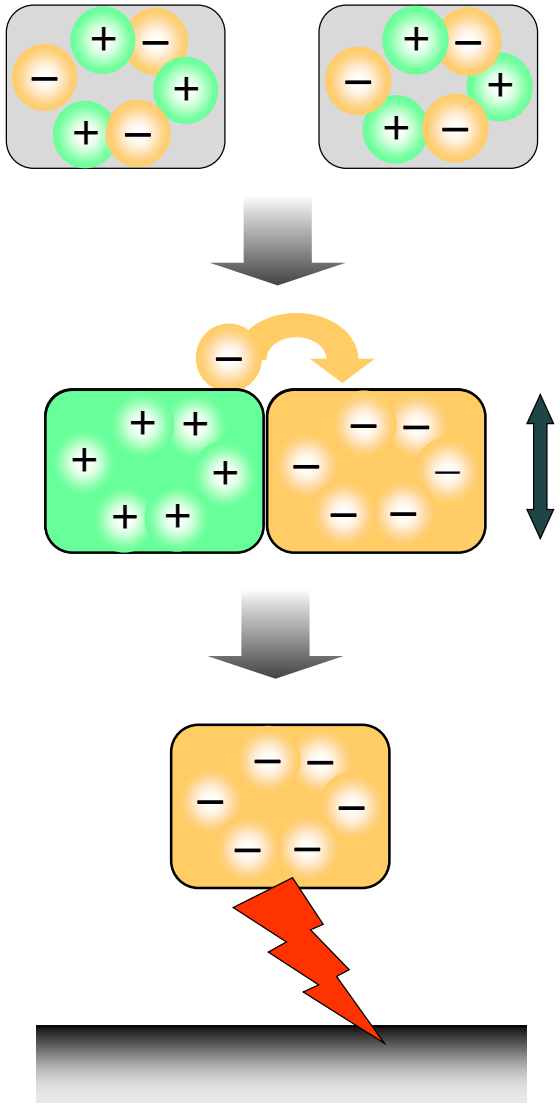

Outside
Inside
H_{out} , E_{out}
Absorption
H_{in} , E_{in}
Reflection
Z_{out}
Z_{screen}
Z_{screen}
Z_{in}

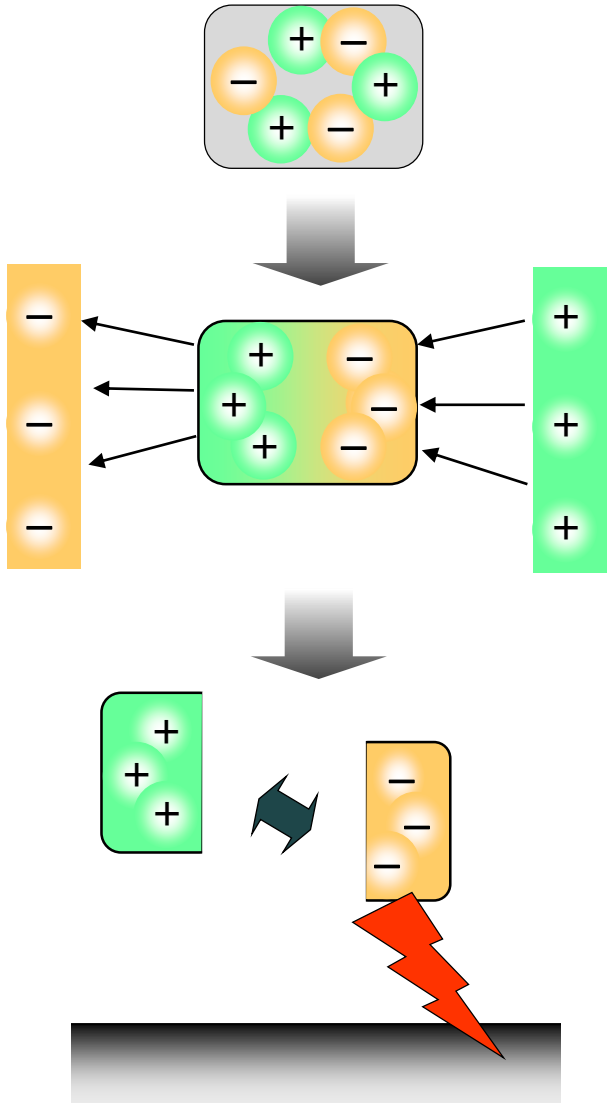

120
dB
100
80
60
40
20
0
A
Steel
Copper
Aluminum
Shield thickness
d = 0.8 mm
1000 000:1
100 000:1
10 000:1
1 000:1
100:1
10:1
1:1
E_out : E_in
H_out : H_in
10^1
10^2
10^3
10^4
10^5
10^6
10^7
Hz
10^8
f

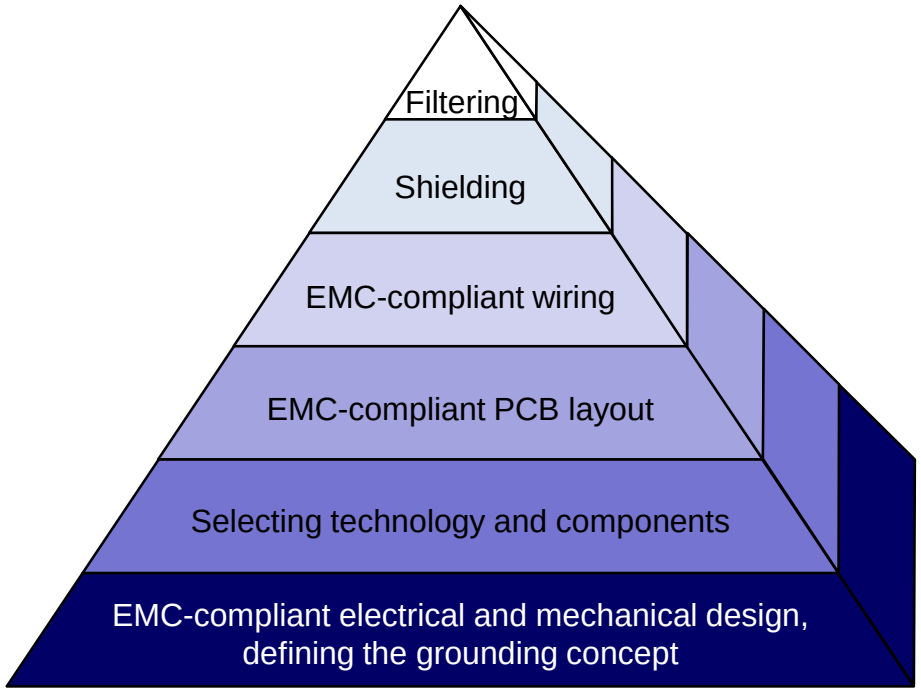

120
dB
100
80
60
40
20
0
A
Steel
Copper
Aluminum
Shield thickness
d = 0.8 mm
1000 000:1
100 000:1
10 000:1
1 000:1
100:1
10:1
1:1
E_out : E_in
H_out : H_in
10^1
10^2
10^3
10^4
10^5
10^6
10^7
Hz
10^8
f

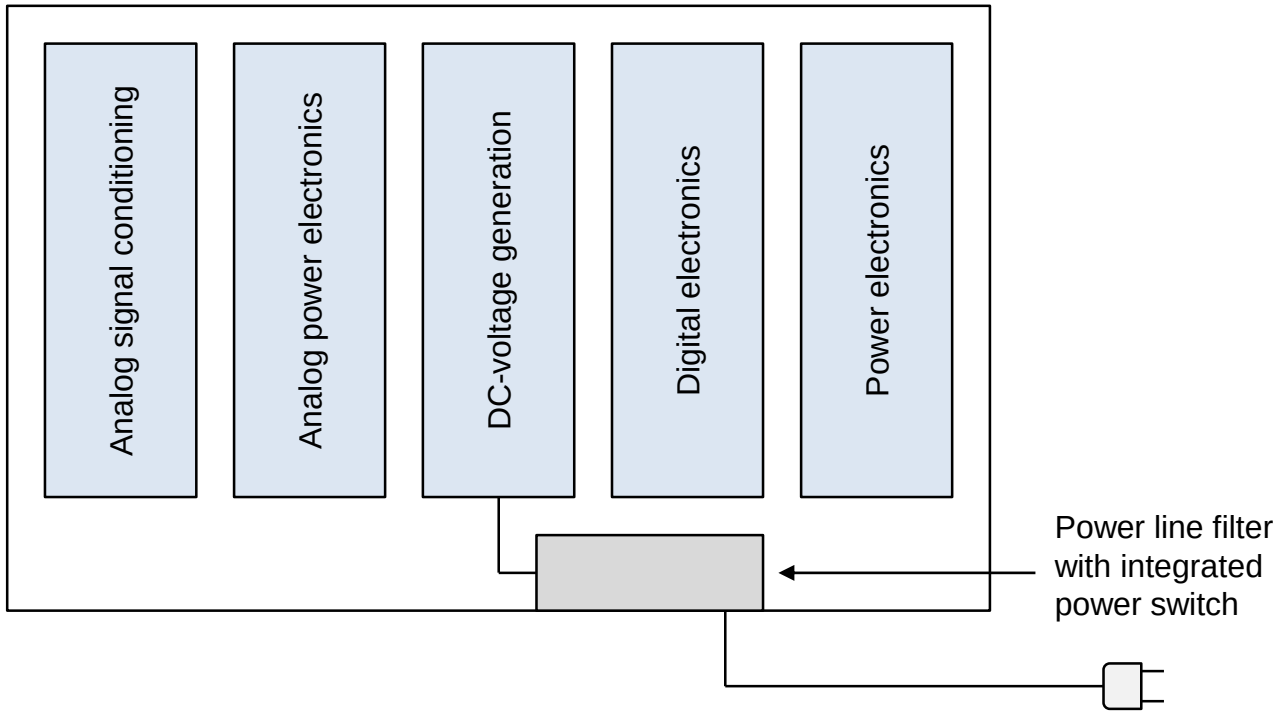

d
L

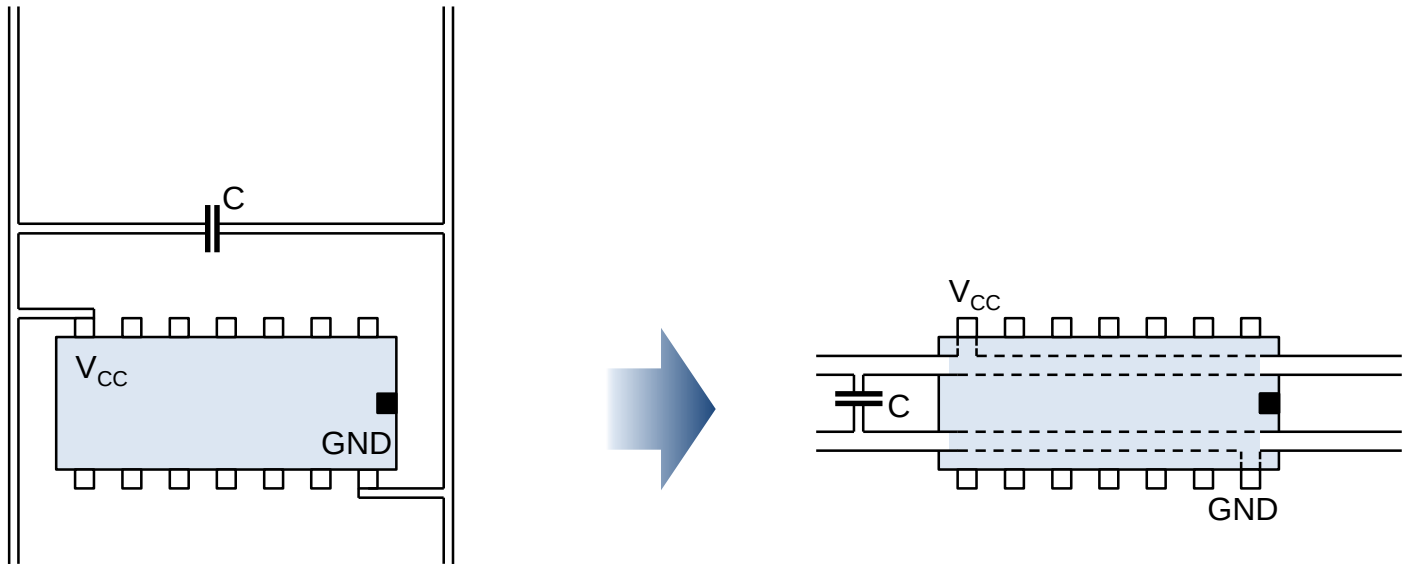


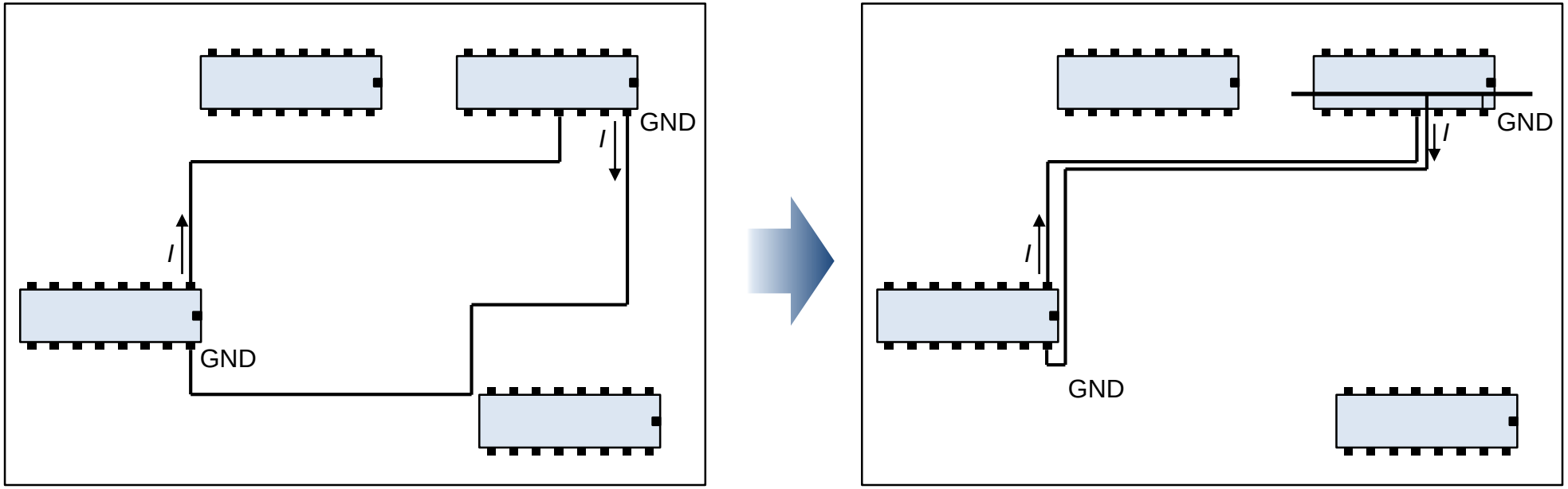


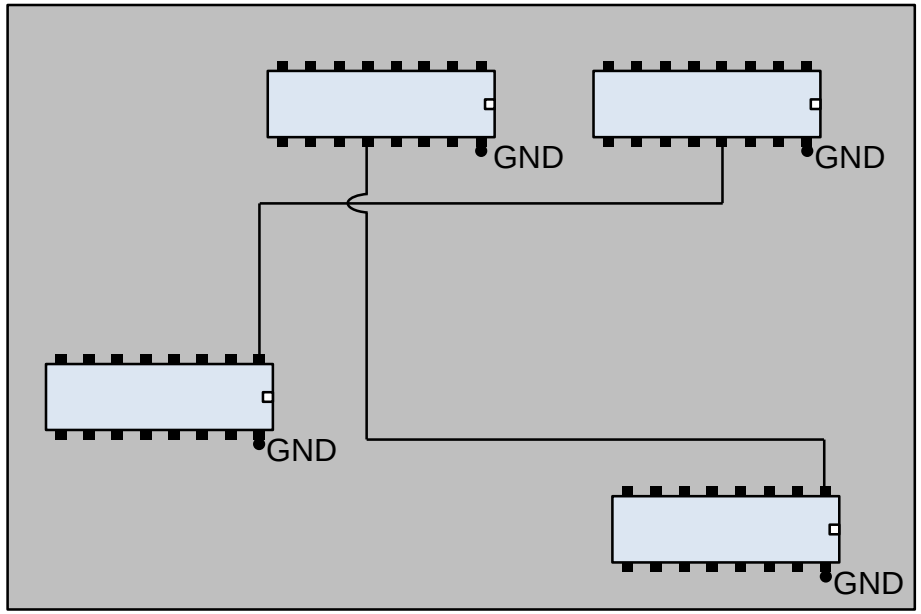


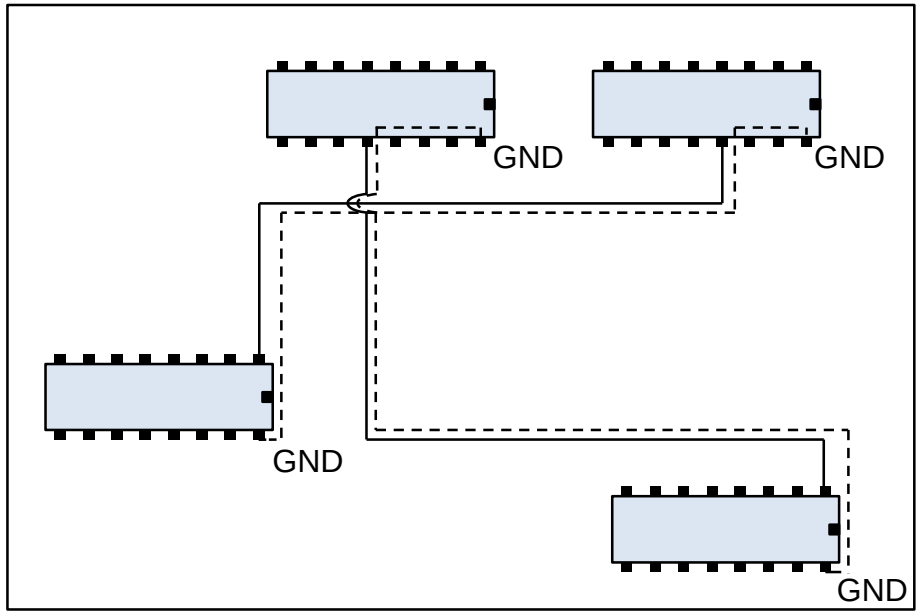

Filtering
Shielding
EMC-compliant wiring
EMC-compliant PCB layout
Selecting technology and components
EMC-compliant electrical and mechanical design,
defining the grounding concept

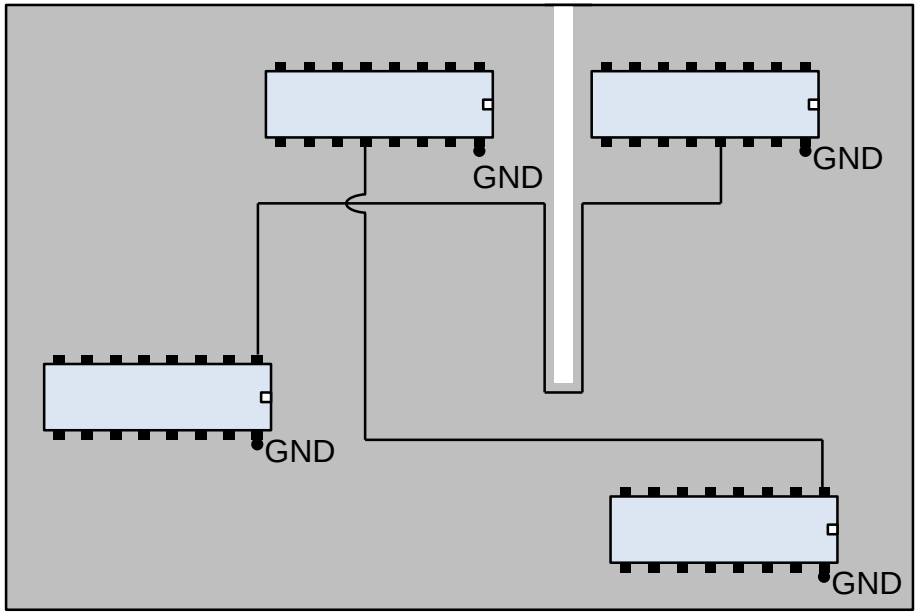

Analog signal conditioning
Analog power electronics
DC-voltage generation
Digital electronics
Power electronics
Power line filter
with integrated
power switch

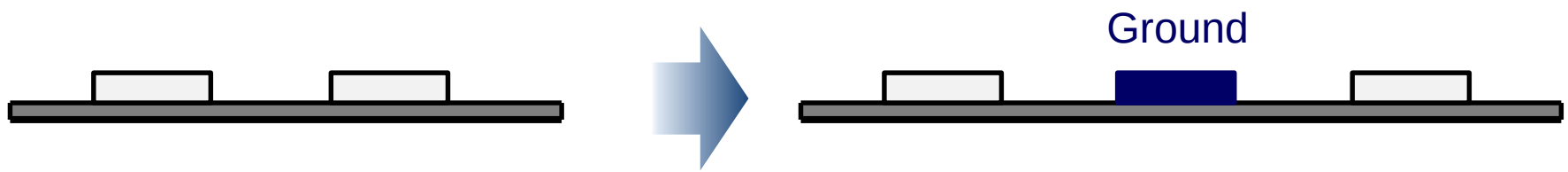

C
V_{CC}
GND
V_{CC}
C
GND

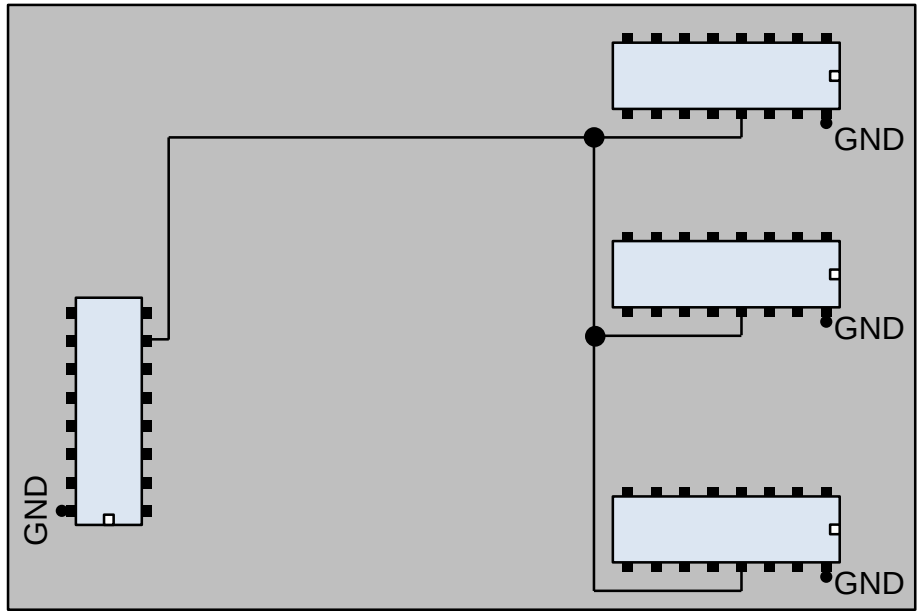

GND
I
I
GND
GND
I
I
GND

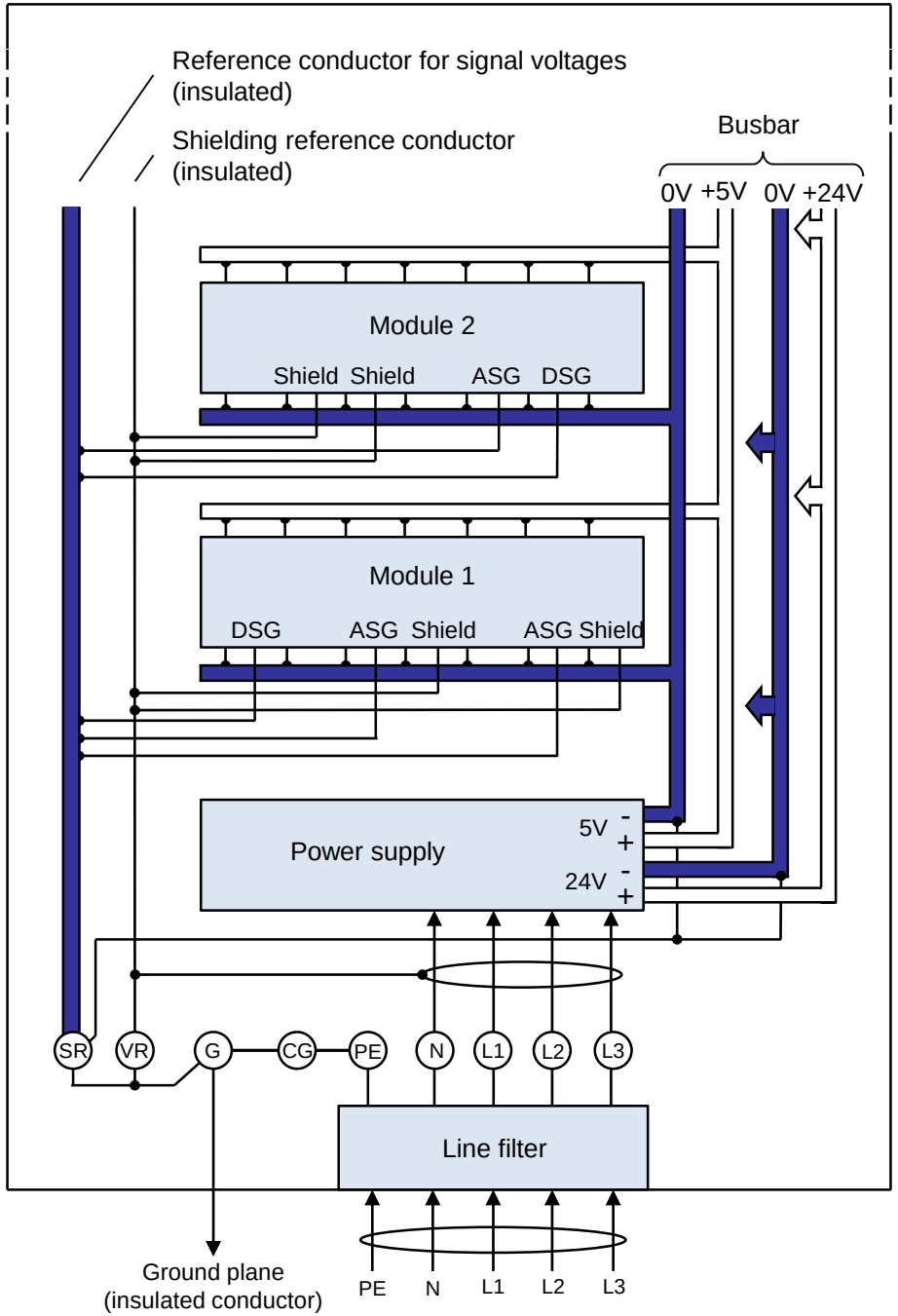

GND
GND
GND
GND

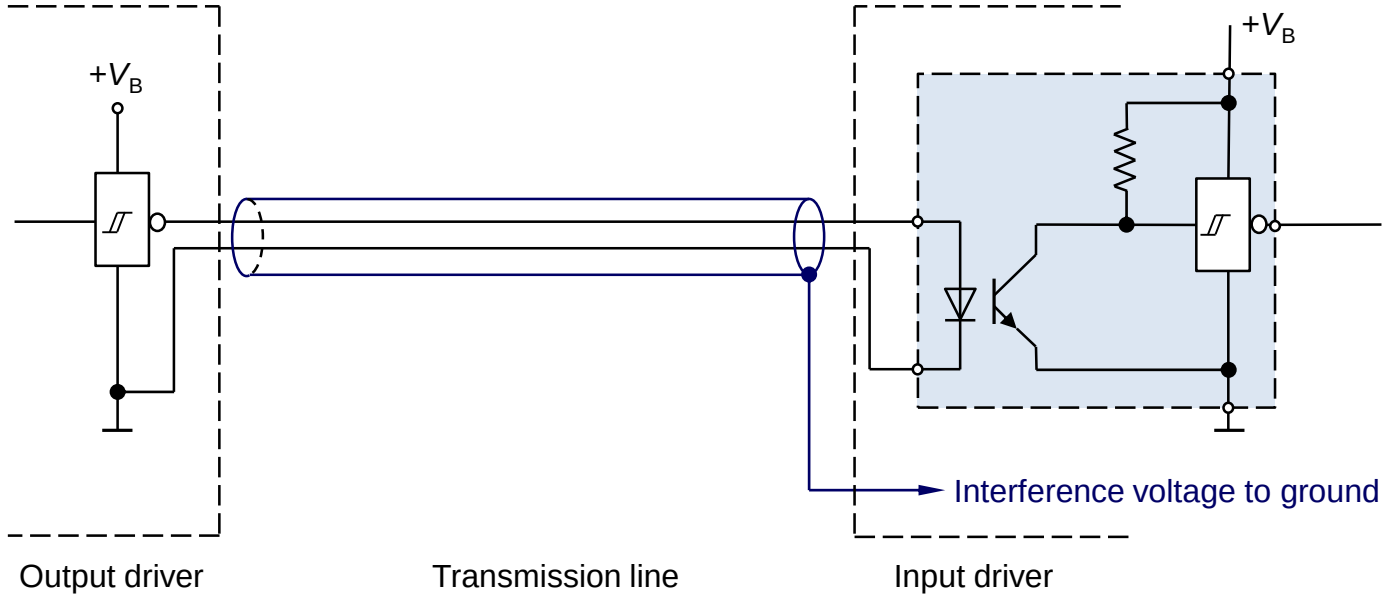

GND
GND
GND
GND


GND
GND
GND
GND


Ground


GND
GND
GND
GND


Reference conductor for signal voltages
(insulated)
Shielding reference conductor
(insulated)
Busbar
0V +5V 0V +24V
Module 2
Shield Shield ASG DSG
Module 1
DSG ASG Shield ASG Shield
Power supply
5V
24V
SR VR G CG PE N L1 L2 L3
Line filter
Ground plane
(insulated conductor)
PE N L1 L2 L3


+V_B
+V_B
Interference voltage to ground
Output driver
Transmission line
Input driver