Transmission Line & Characteristic Impedance

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Transmission line and characteristic impedance

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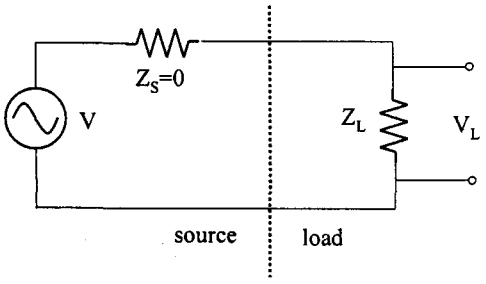
transmission-line and characteristic impedance

1. impedance matching and maximum power transfer

- To get maximum power at a load, the load impedance should be same as source impedance (for real impedance), or conjugate impedance (for complex impedance)

1) ideal voltage source : Z_S (source impedance) = 0
Z_L (load impedance) = 0



P_L (available power at load Z_L) =

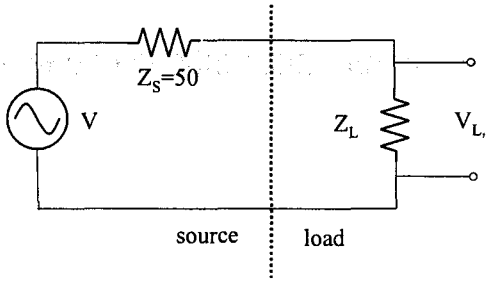
$$\frac{V_L^2}{Z_L} = \frac{V^2}{Z_L}$$

when $Z_L \rightarrow 0$, $P_L \rightarrow \infty$

transmission-line and characteristic impedance

1. impedance matching and maximum power transfer

2) 50Ω source : Z_S = 50Ω, Z_L = 50Ω



$$P_L = (V_L)^2 \times \frac{1}{Z_L}$$

$$Z_{L1} = 50\Omega, \quad P_{L1} = \left(\frac{V}{2}\right)^2 \times \frac{1}{50} = \frac{V^2}{200} = P_{MAX}$$

$$Z_{L2} = 25\Omega, \quad P_{L2} = \left(\frac{V}{3}\right)^2 \times \frac{1}{25} = \frac{V^2}{225} = \frac{8}{9} \times P_{MAX}$$

$$Z_{L3} = 100\Omega, \quad P_{L3} = \left(\frac{2V}{3}\right)^2 \times \frac{1}{100} = \frac{V^2}{225} = \frac{8}{9} \times P_{MAX}$$

$$Z_{L4} = 0\Omega, \quad P_{L4} = (0)^2 \times \frac{1}{0} = 0$$

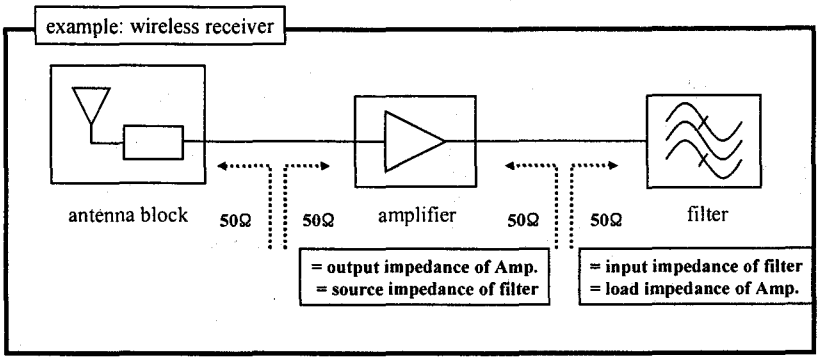
$$Z_{L5} = \infty\Omega, \quad P_{L5} = (V)^2 \times \frac{1}{\infty} = 0$$

transmission-line and characteristic impedance

2. in 50Ω system

- When we are to connect several blocks in series (cascade), all input and output impedance of the blocks should be 50Ω.
  We say that "**matched to 50Ω**".

1) for direct connection without any matching (interface) network



transmission-line and characteristic impedance

2. in 50Ω system

2) How exactly should your circuit be matched to 50Ω? It depends on several requirements of your system, which are input or output return loss, VSWR, etc.

return loss

$when \quad Z_L = 25\Omega \ or \ 100\Omega, \ P_L = \frac{8}{9} \ of \ P_{MAX} \Rightarrow$

$return \ loss = \frac{1}{9} \ of \ P_{MAX} = 10\log\frac{1}{9} \cong -9.5dB$

reflection coefficient, Γ

$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S} = \frac{25-50}{25+50} \ or \ \frac{100-50}{100+50} = -\frac{1}{3} \ or \ \frac{1}{3}$

$-\frac{1}{3}$: − *means phase shift of* $180°$ *or* $\frac{\lambda}{2}$

$\rightarrow$ *in dB*: $20\log|\Gamma| = 20\log\frac{1}{3} \cong -9.5dB$

VSWR (voltage standing wave ratio)

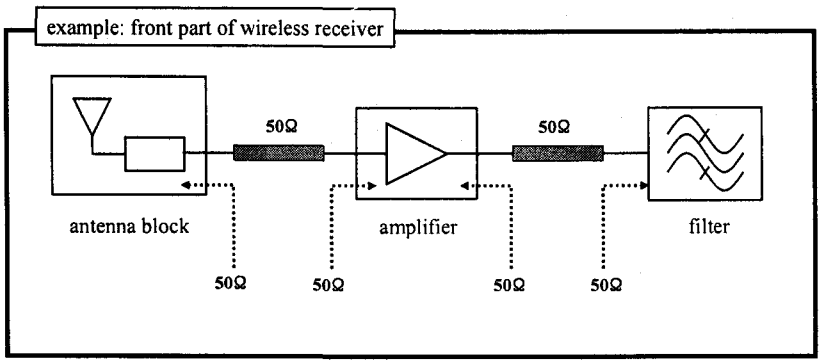
$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+1/3}{1-1/3} = 2$

transmission-line and characteristic impedance

3. interconnection

- To construct a complete system, many blocks should be interconnected.
- Consider that all blocks are matched to 50Ω.

1) The interconnection should be completed by 50Ω transmission line



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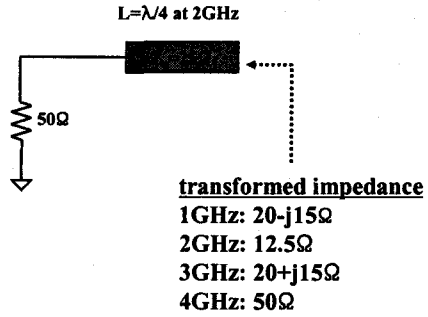
3. interconnection

2) If the lines are not 50Ω, they cause impedance transform and impedance mismatch. Suppose a 25Ω transmission line which has the length of 1/4 wavelength at 2GHz.



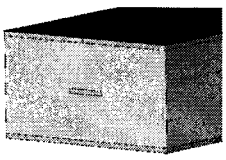
➧ Impedance mismatch causes **reflection , power loss, undesired radiation, cross-talk (coupling), noise, etc.** and these lead degraded system.

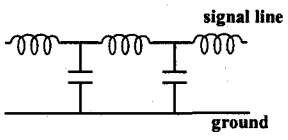
transmission-line and characteristic impedance

4. characteristic impedance, Z_0

1) Signal line paired with ground has its own characteristic impedance due to their series inductance of signal line and shunt capacitance between signal line and ground.

ex) strip line, microstrip line, ...



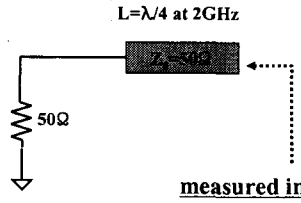


*** Lines without paired ground act as inductors.**

transmission-line and characteristic impedance

4. characteristic impedance, Z_0

2) 50Ω (transmission) line: the characteristic impedance of the line is 50Ω

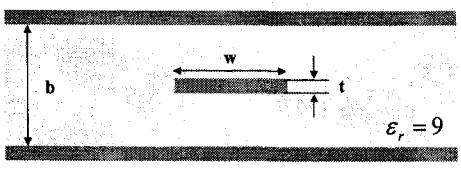


measured impedance
1GHz: 50Ω
2GHz: 50Ω
3GHz: 50Ω
for all frequency: 50Ω

transmission-line and characteristic impedance

4. characteristic impedance, Z_0

3) suppose a stripline in LTCC board (relative permittivity=9, t=1um)



t: thickness of signal line
w: width of signal line
b: distance between two ground plane

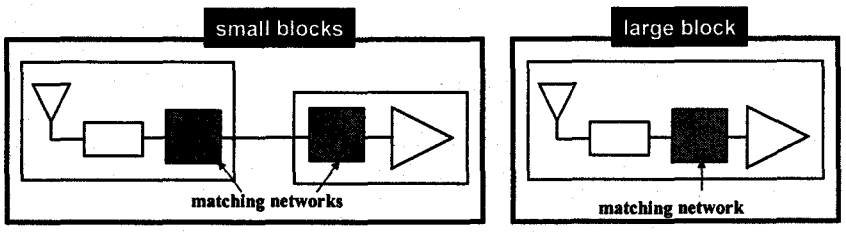
Table 1	w=100um			
b (um)	50	100	400	**487**
$Z_0(\Omega)$	12.4	21.3	46.2	**50**

Table 2	b=50um			
w (um)	100	50	10	**8.6**
$Z_0(\Omega)$	12.4	21.9	47.5	**50**

transmission-line and characteristic impedance

5. advantages of SIP (system in package)

1) Each blocks have input and output matching networks.
As shown below, large block needs fewer matching networks than small ones.



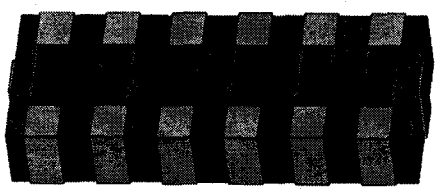
2) Large block reduces the line length and it is helpful for noise not being radiated. Because longer lines radiate more electromagnetic energy.

3) The shorter line length, the lesser variation of impedance.

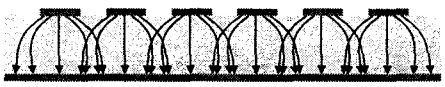
transmission-line and characteristic impedance

6. disadvantage of SIP

1) Smaller size may produce more cross-talking (coupling) even when a circuit is perfectly matched because imperfect shield causes coupling of electromagnetic field. Close and parallel lines can make this problem.



6-array EMI filter (product of one of companies in Korea)



E-field of paralleled 6 microstrip lines

E-field of paralleled 3 microstrip lines with shield

2) They need shield (ground) and shield pins for better quality but these increase the product's size and cost. This is a trade-off.

transmission-line and characteristic impedance

7. several considerations in integration and packaging

1) how to meet the line impedance with given conditions (example: 4-3)

2) how to minimize the length of interconnections

3) how to reduce the cross-talk even in smaller size

4) Standardization should be considered for circuit engineers who are consumers of modules and components in order to they use them easily.
But market leaders usually do not care of standardization.
Just their specification becomes standards.

standardization issues: physical dimension (5045, 2012, 1005, etc.)
terminal pitch
electrical characteristics
supply voltage, etc.