First interactive lecture of Topic 4: Transceiver and noise

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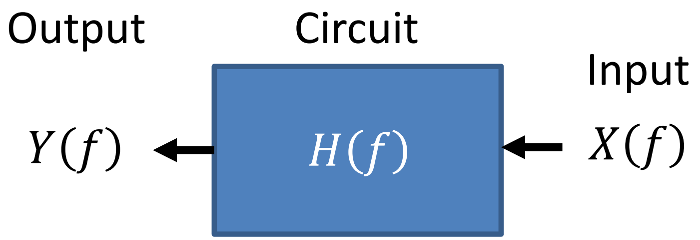
Katsuyuki Haneda

Department of Electronics and Nanoengineering

This lecture covers Pozar Chapters 10.1-3, 13.5 and 14.2.

Linear and non-linear circuits



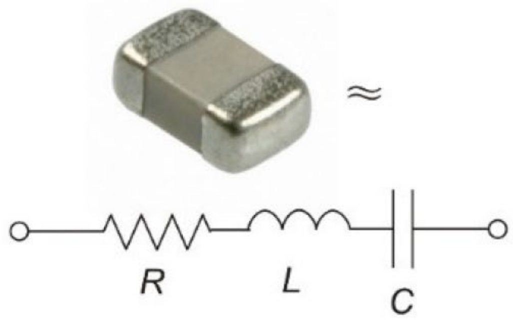
$$Y(f) = a_0 + a_1 X(f) + a_2 X^2(f) + \ldots$$

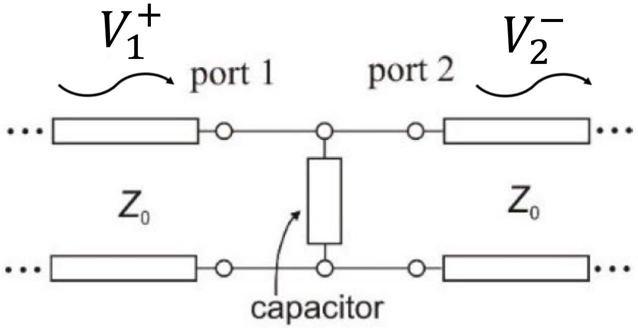
Linear response

Non-linear response

- Linear circuits
  - E.g., resistance, inductance and capacitance, i.e., passive components
  - Output is always proportional to inputs at any frequency
  - Scattering parameter does NOT change depending on input power level
  - $Y(f) = X(f)H(f) \rightarrow aX(f)H(f) = aY(f)$
- Non-linear circuits
  - E.g., diodes, operational amplifiers and transistors, i.e., active components
  - Scattering parameter depends on input power level
  - $Y(f) = X(f)H(f) \rightarrow aX(f)H(f) \neq aY(f)$

For example, the band-stop filter we studied in exercise 3.1 is a linear circuit.

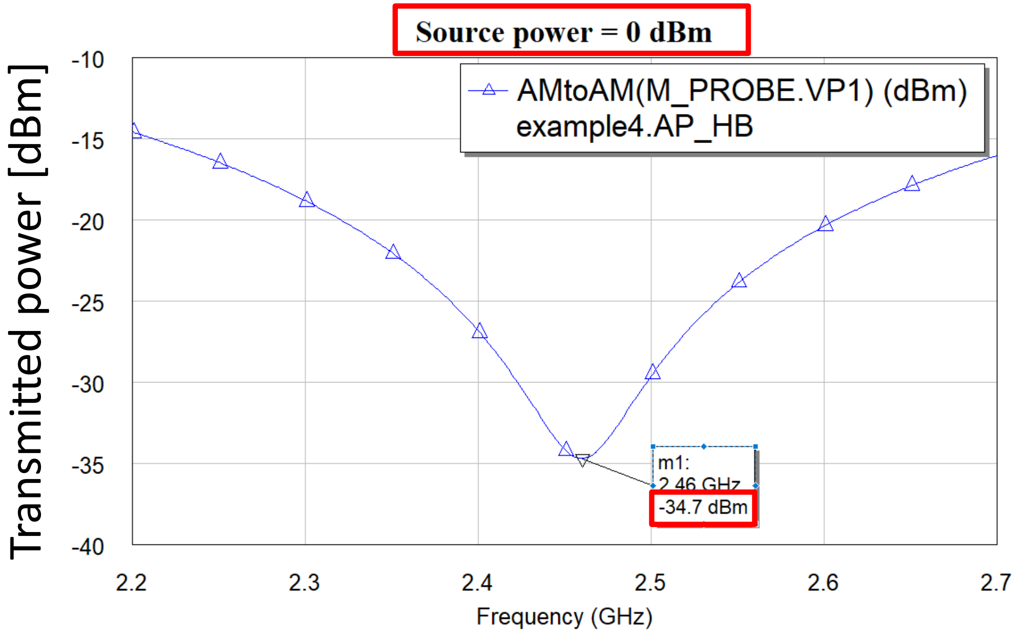


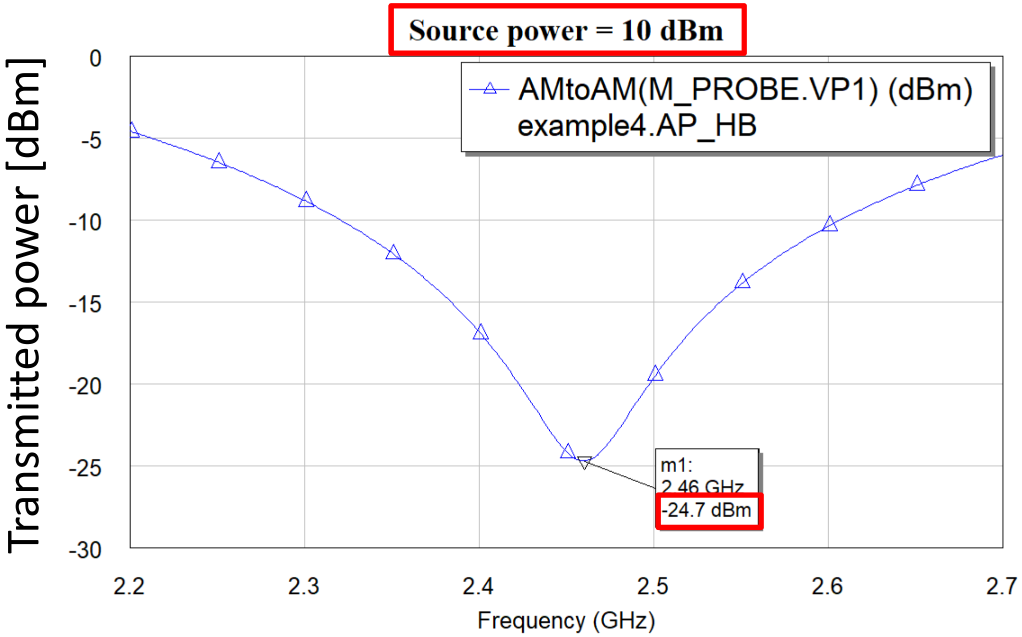


$$\boxed{V_2^- = T V_1^+}$$

where

$$T = 1 + \Gamma = 1 + \frac{Z_{\text{chip}} - Z_0}{Z_{\text{chip}} + Z_0}$$
$$= 1 + \frac{R + \mathrm{j}\left(\omega L - \frac{1}{\omega C}\right) - Z_0}{R + \mathrm{j}\left(\omega L - \frac{1}{\omega C}\right) + Z_0}$$

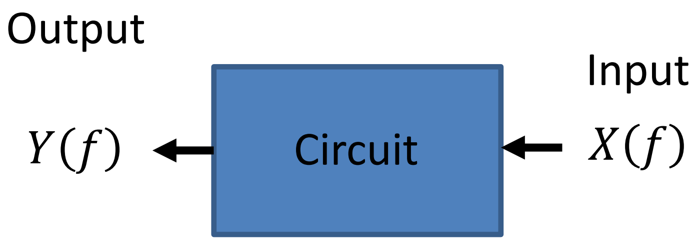




Shape of receive spectrum remains the same, regardless of the source power.

Q1: The patch antenna, we studied in exercise 3.2, is …

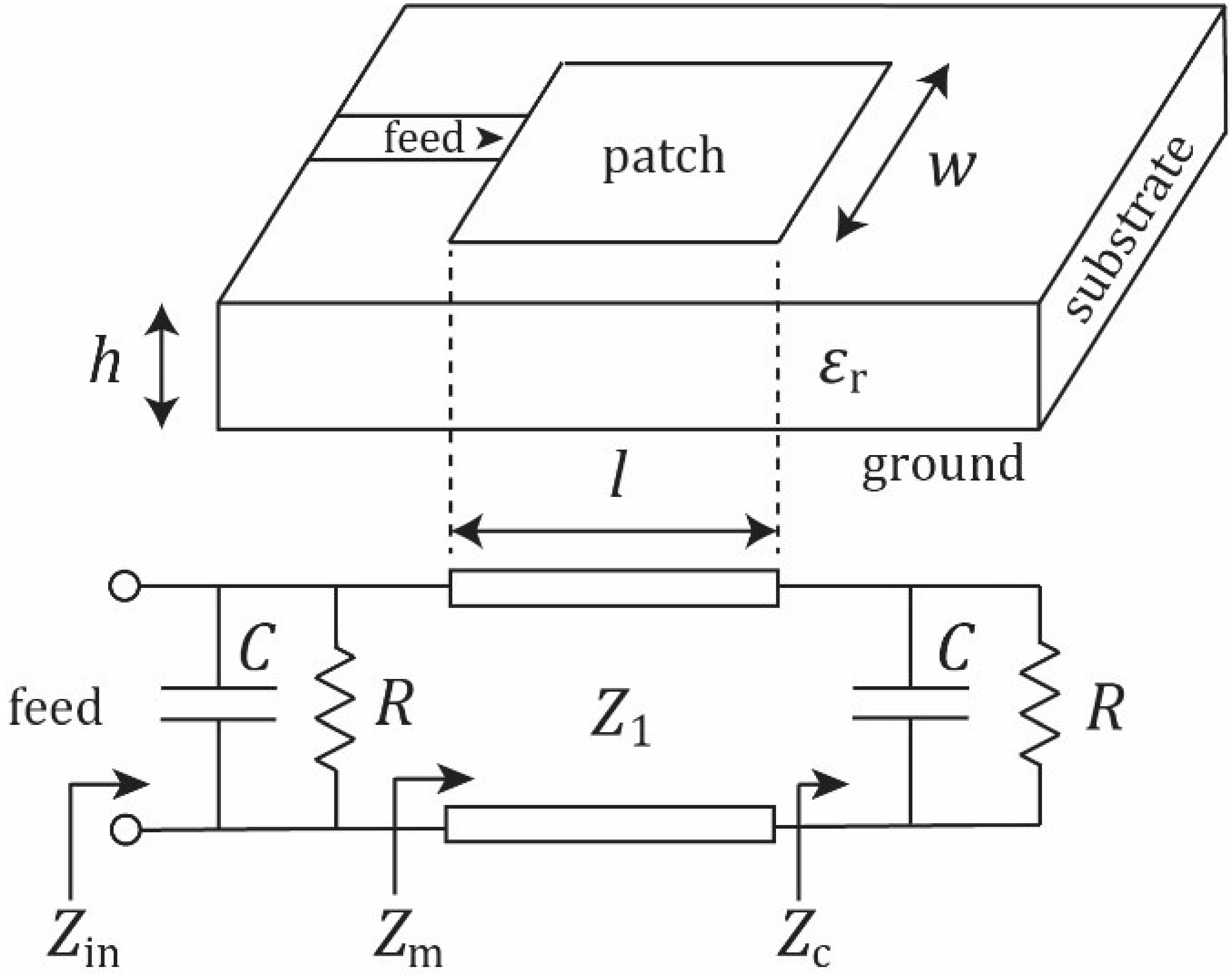
1. A linear circuit.
2. A non-linear circuit.
3. I do not know which one to choose.



$$Y(f) = a_0 + a_1 X(f) + a_2 X^2(f) + \ldots$$

Linear response

Non-linear response

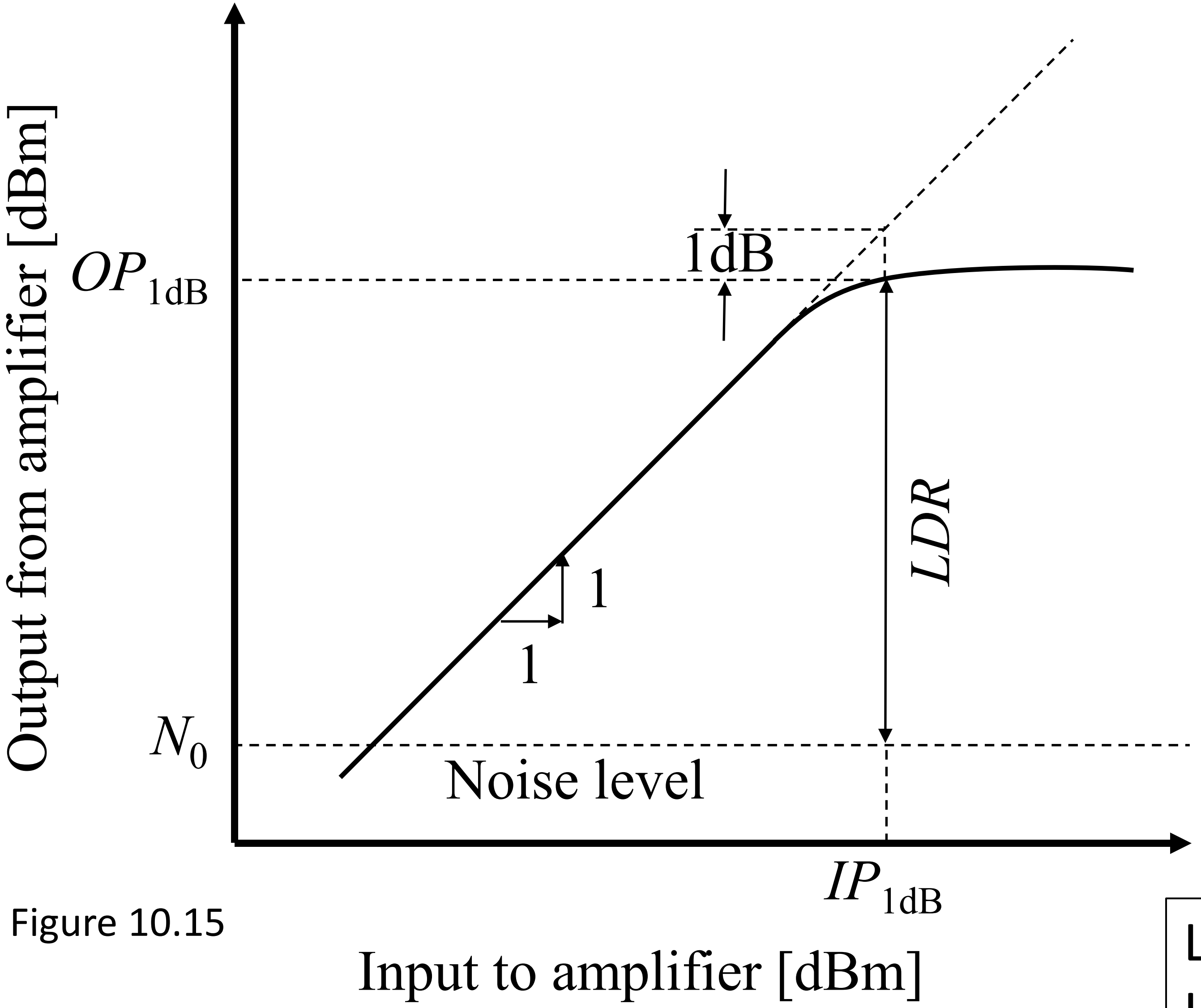


Q2: Non-linear electric components, e.g., diodes, are usually **not** used as the following microwave circuits. Choose 5. if you do not know what to choose.

1. Mixers.
2. Amplifiers.
3. Filters.
4. Detectors.
5. I do not know which one to choose.

Pozar Chapters 10.3 and 13.5

Characterization of amplifier (1): Single tone input



Pozar, Figure 10.15

$$v_\mathrm{o} = a_0 + a_1 v_\mathrm{i} + a_2 v_\mathrm{i}^2 + a_3 v_\mathrm{i}^3 + \cdots$$

$$v_\mathrm{i} = V_0 \cos \omega_0 t$$

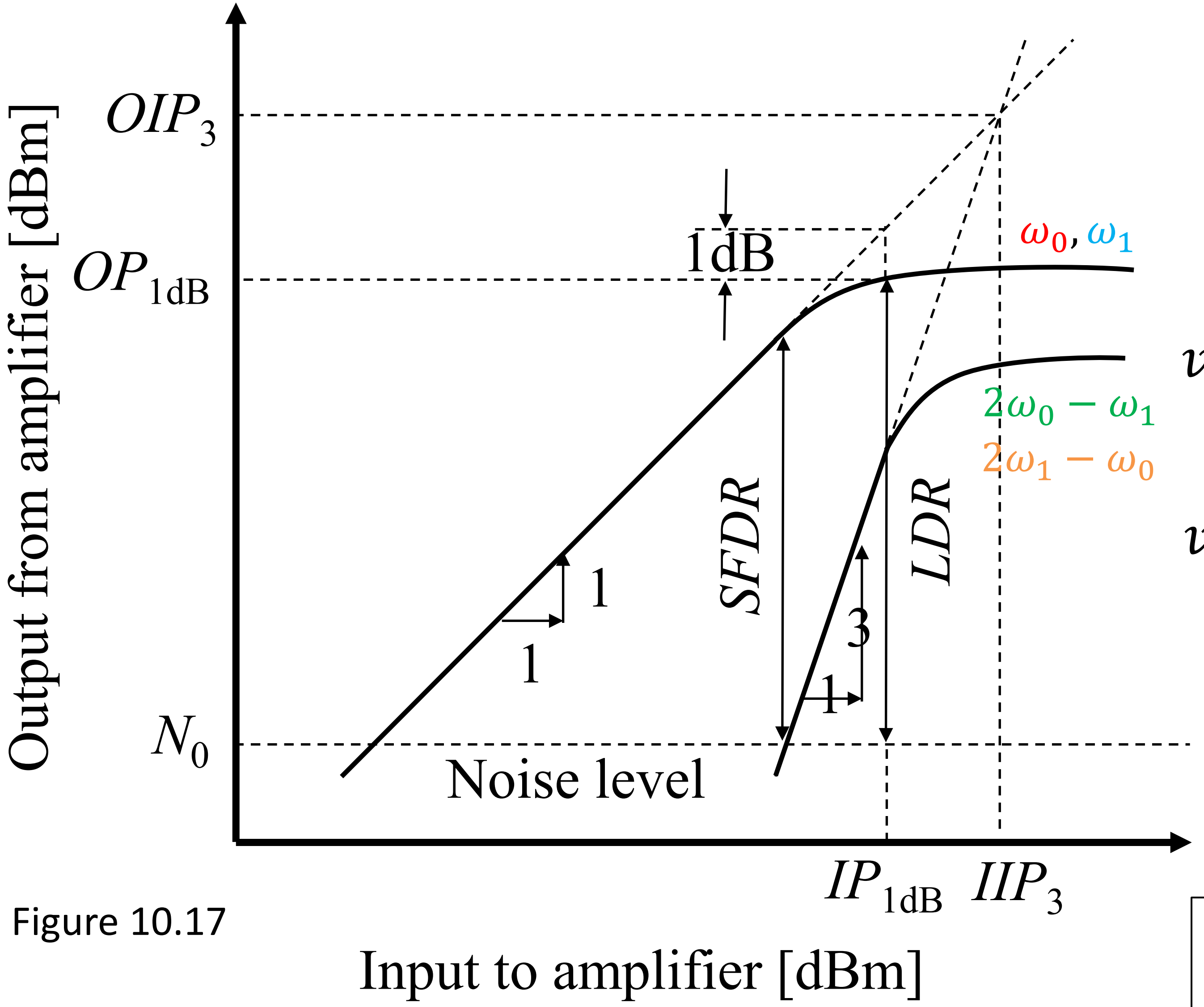
$$v_\mathrm{o}\Big|_{\omega=\omega_0} = a_1 V_0 + \frac{3}{4} a_3 V_0^3$$

$$\Rightarrow \quad G_\mathrm{v} = \frac{v_\mathrm{o}}{v_\mathrm{i}}\Big|_{\omega=\omega_0} = a_1 + \frac{3}{4} a_3 V_0^2$$

where usually a_3 has an opposite sign to a_1.

LDR = Linear Dynamic Range
IP = Input Power, OP = Output Power

Characterization of amplifier (2): Two-tone input



Pozar, Figure 10.17

$$v_o = a_0 + a_1 v_i + a_2 v_i^2 + a_3 v_i^3 + \cdots$$

$$v_i = V_0(\cos \omega_0 t + \cos \omega_1 t),\ \ \omega_0 \sim \omega_1$$

$$v_o\Big|_{\omega=\omega_0} = v_o\Big|_{\omega=\omega_1} = a_1 + \frac{3}{4} a_3 V_0^3$$

$$v_o\Big|_{\omega=2\omega_1-\omega_0} = v_o\Big|_{\omega=2\omega_0-\omega_1} = \frac{3}{4} a_3 V_0^3$$

where

- a_3 has an opposite sign to a_1.
- $2\omega_1 - \omega_0 \sim 2\omega_0 - \omega_1 \sim \omega_0, \omega_1$.

SFDR = Spurious-Free Dynamic Range
IIP3 = Third-order Intercept Point

Pozar Chapter 13.5

Characterization of mixer

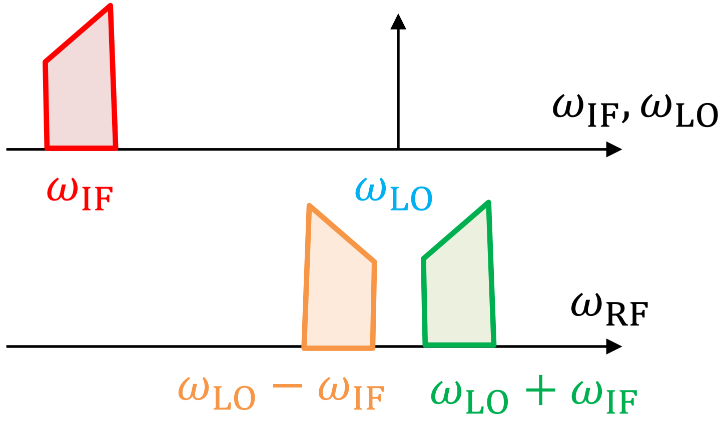
Mixer input-output relationship $v_{\mathrm{o}} = \cdots + a_2 v_{\mathrm{i}}^2 + \cdots$

Up-conversion in the transmitter

$$v_{\mathrm{i}} = V_0(\cos \omega_{\mathrm{IF}} t + \cos \omega_{\mathrm{LO}} t),\ \ \omega_{\mathrm{IF}} \ll \omega_{\mathrm{LO}}$$

$$v_{\mathrm{o}}\Big|_{\omega=\omega_{\mathrm{LO}}-\omega_{\mathrm{IF}}} = v_{\mathrm{o}}\Big|_{\omega=\omega_{\mathrm{LO}}+\omega_{\mathrm{IF}}} = a_2 V_0^2$$

Lower side band (LSB)   Upper side band (USB)



Down-conversion in the receiver

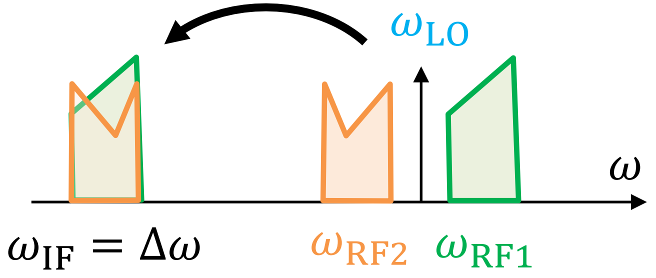
$$v_{\mathrm{i}} = V_0(\cos \omega_{\mathrm{RF1}} t + \cos \omega_{\mathrm{LO}} t),$$

$$\omega_{\mathrm{RF1}} - \omega_{\mathrm{LO}} = \Delta\omega$$

$$v_{\mathrm{i}} = V_0(\cos \omega_{\mathrm{RF2}} t + \cos \omega_{\mathrm{LO}} t),$$

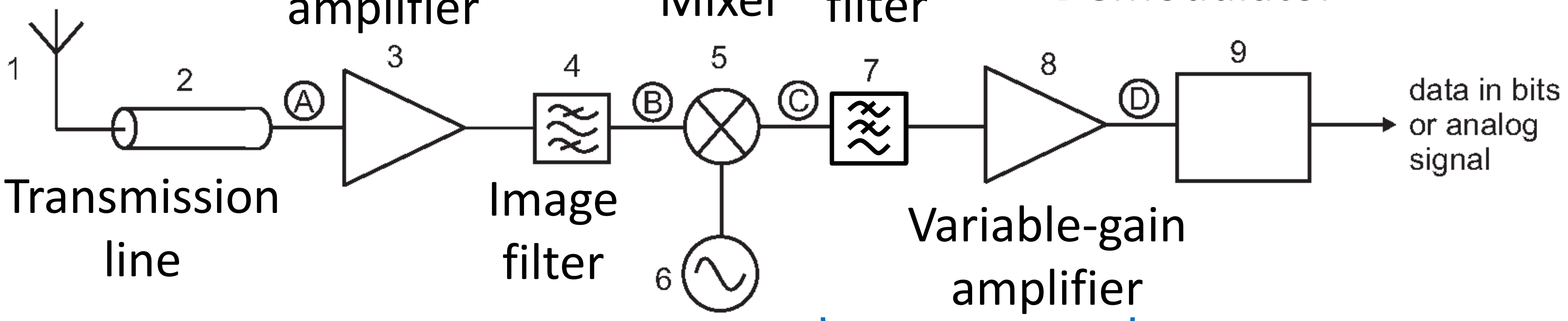
$$\omega_{\mathrm{RF2}} - \omega_{\mathrm{LO}} = -\Delta\omega$$

$$v_{\mathrm{o}} = \cdots + a_2 V_0^2\{\cos(\omega_{\mathrm{RF1}} - \omega_{\mathrm{LO}}) \ \dots$$
$$+ \cos(\omega_{\mathrm{RF2}} - \omega_{\mathrm{LO}})\}$$



Homodyne / Direct-conversion receiver

(Example structure)



Antenna

Low-noise amplifier

Mixer

Low-pass filter

Demodulator

Transmission line

Image filter

Variable-gain amplifier

Local oscillator

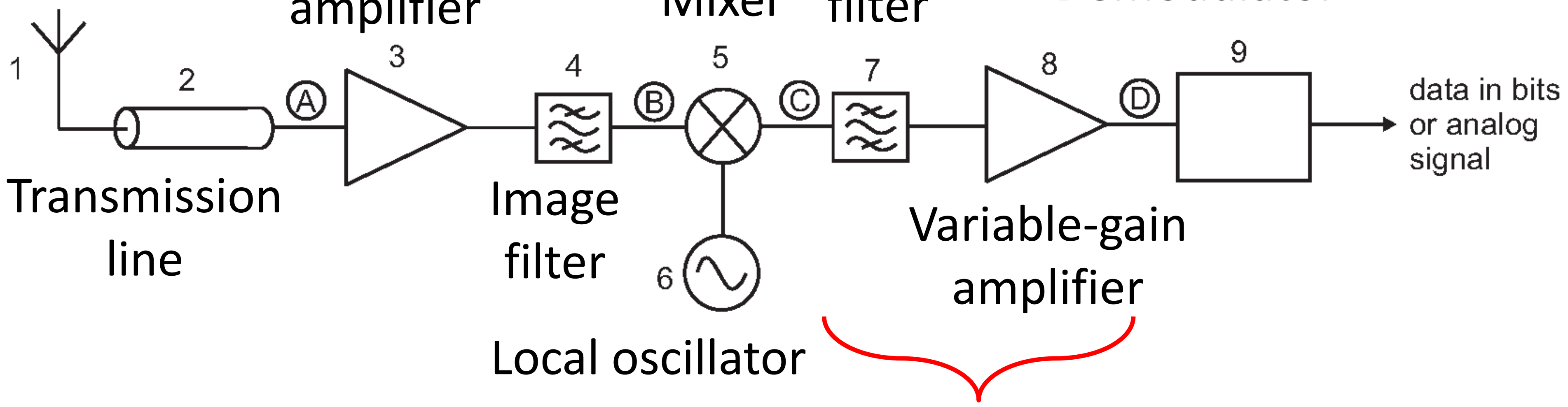
$f_{\mathrm{RF}} = f_{\mathrm{LO}}$

Baseband $f_{\mathrm{IF}} = 0$

Similar figure in
Pozar, Figure 14.12

Superheterodyne receiver

(Example structure)



Antenna

Low-noise amplifier

Mixer

Channel filter

Demodulator

Transmission line

Image filter

Variable-gain amplifier

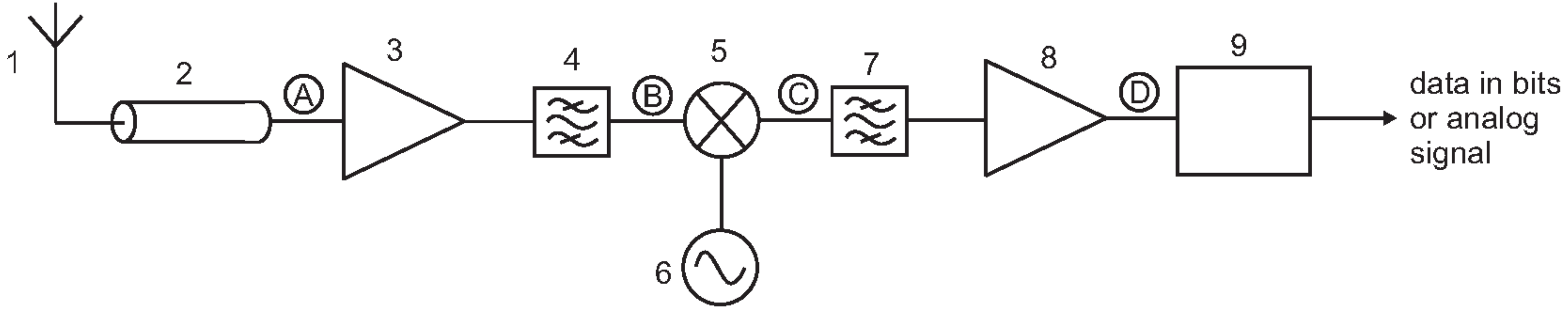
Local oscillator

$f_{\mathrm{RF}} > f_{\mathrm{LO}}$

Baseband $f_{\mathrm{IF}} > 0$

Similar figure in
Pozar, Figure 14.13

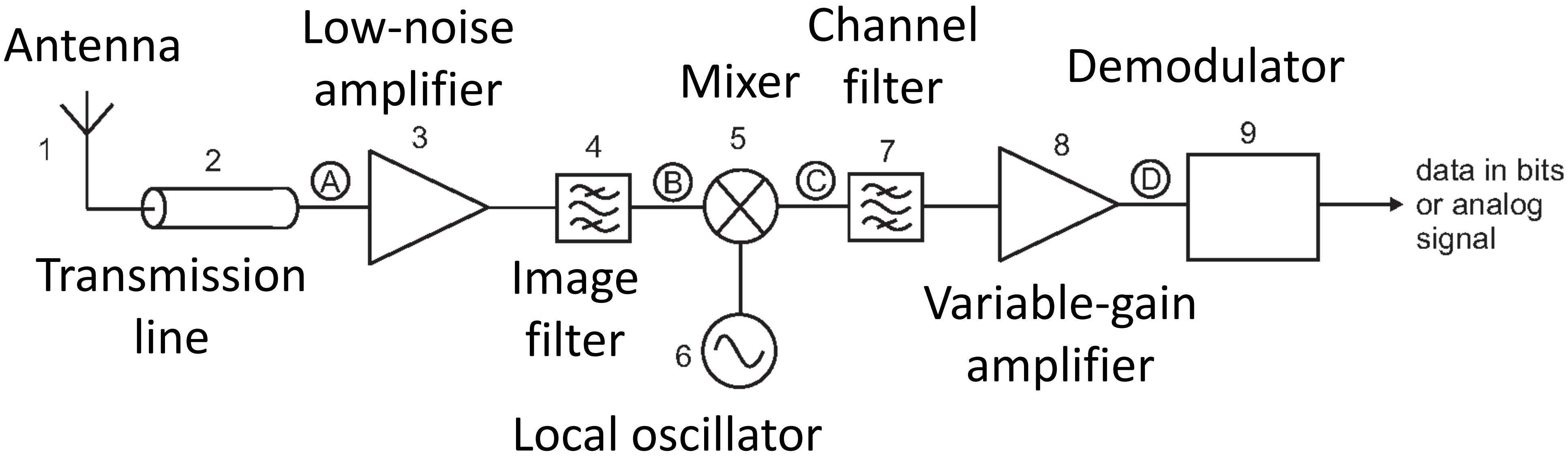
Q3: The following explains each component of the superheterodyne receiver. Choose an **incorrect explanation**. Choose 5. if you do not know what to choose.



1. The image filter removes the mirror spectrum of the signal of interest.
2. The channel filter is usually implemented at the radio frequency stage for ease of implementation.
3. The low-noise amplifier is operated either in linear or saturation regions in practical radio systems.
4. The local oscillator can tune frequencies to select a frequency of interest with a fixed band-pass filter.
5. I do not know which explanation is incorrect.

Sources of thermal noise

Which components add noise?



Antenna

Low-noise amplifier

Mixer

Channel filter

Demodulator

Transmission line

Image filter

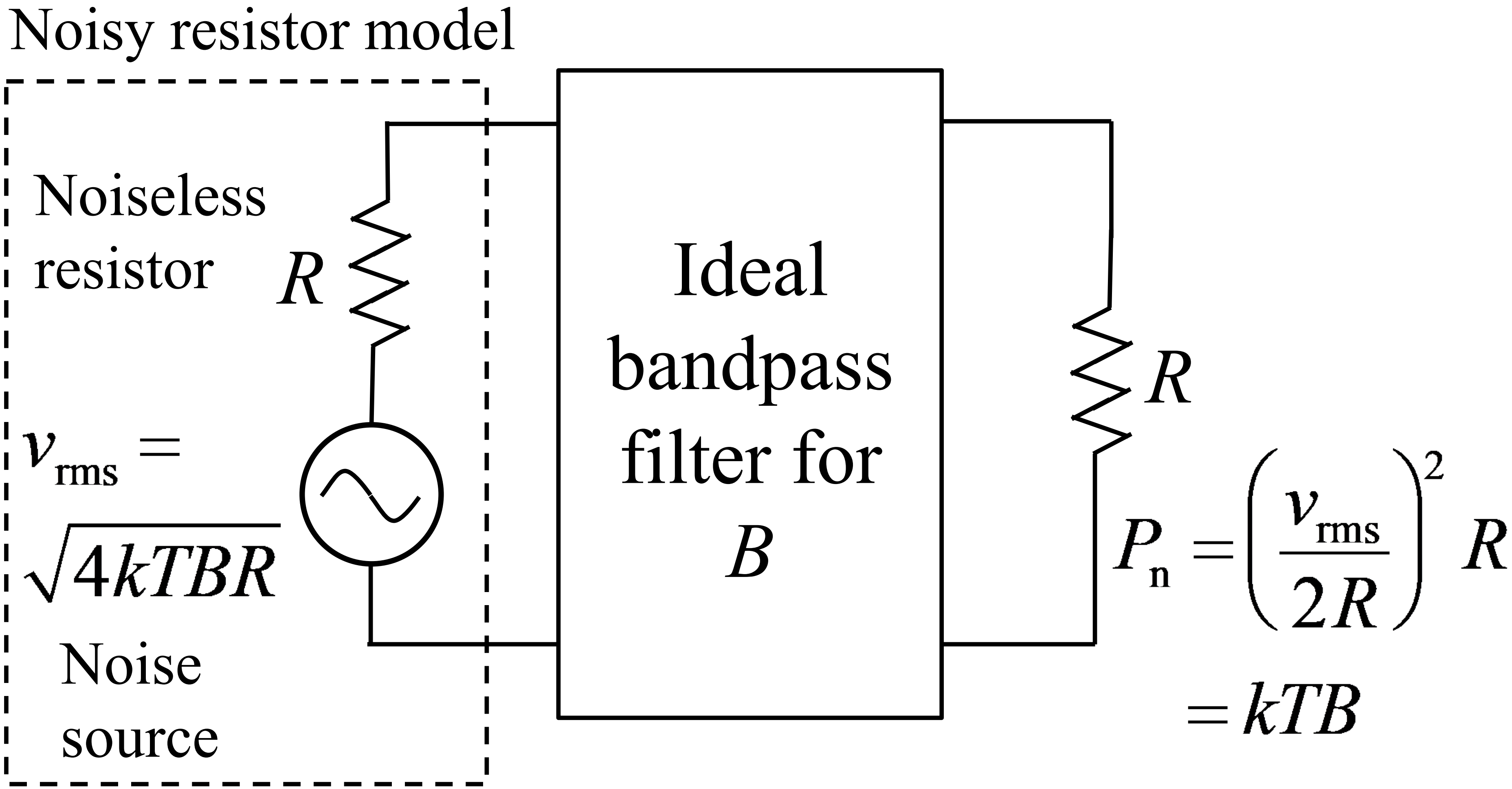
Variable-gain amplifier

Local oscillator

Pozar, Figure 14.13

Any resistor components generate noise!

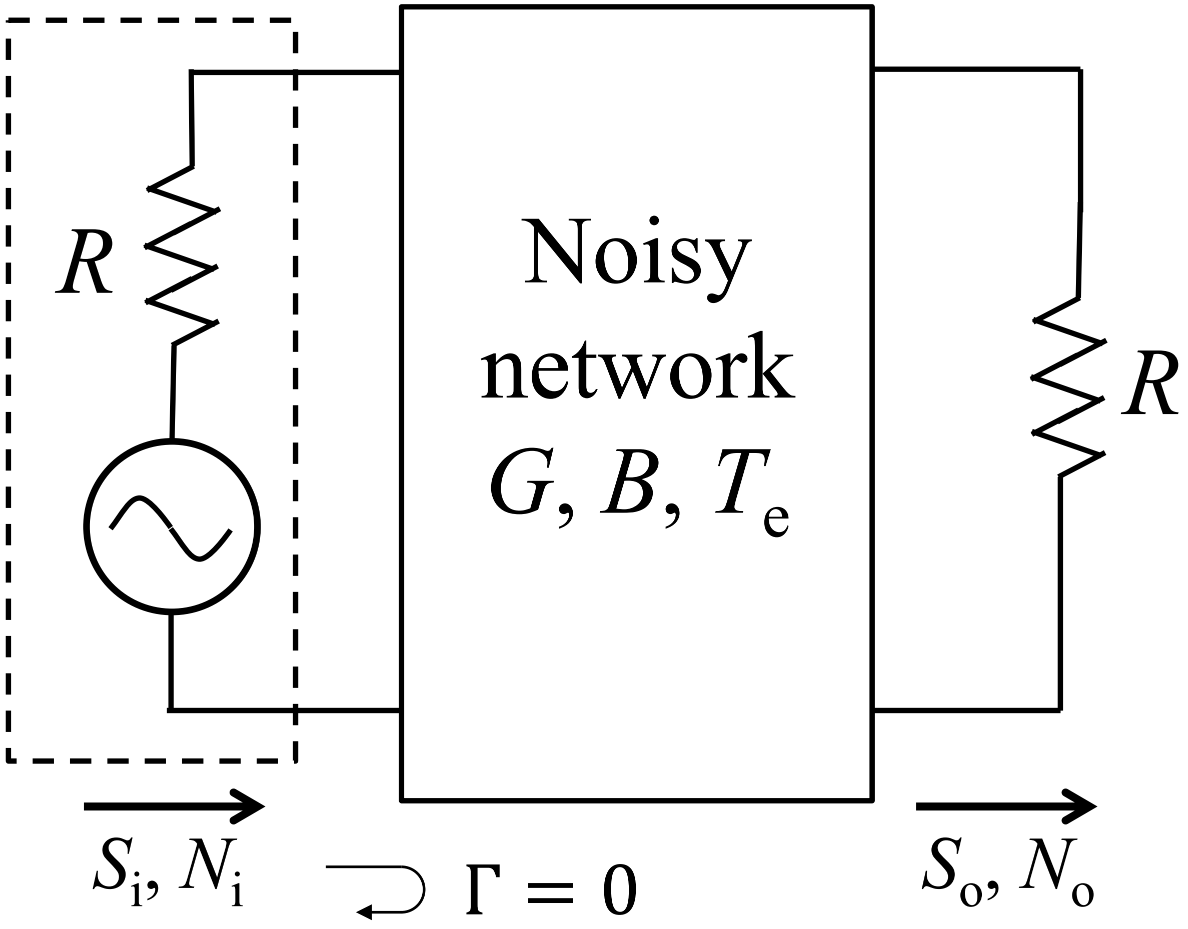
Equivalent circuit model of a resistor



Pozar Chapter 10.1

Noise temperature and figure: Definition

T_0 = 290K as a reference!



$$F = \frac{S_i / N_i}{S_o / N_o}$$

$$= 1 + \frac{T_e}{T_0}$$

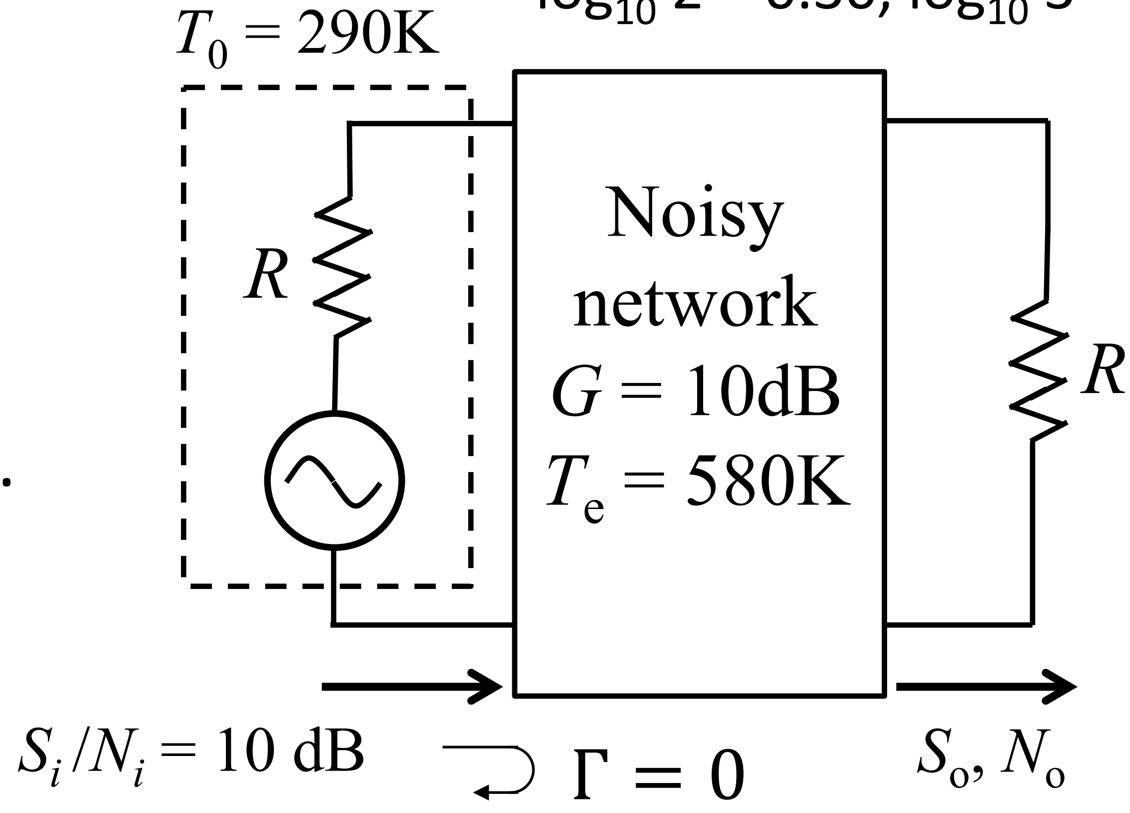
Noise temperature is defined at T_0 = 290 K input noise temperature. NOT applicable when the input noise temperature $T_0 \neq 290$ K!

Pozar Chapter 10.2

Q4: What is the output signal-to-noise ratio S_o / N_o of the two-port network?

1. 7.0 dB.
2. 15.3 dB.
3. 17.0 dB.
4. 5.3 dB.
5. I do not know.

$\log_{10} 2 = 0.30$, $\log_{10} 3 = 0.47$



Q5: What is the equivalent noise temperature of a transmission line, T_e?

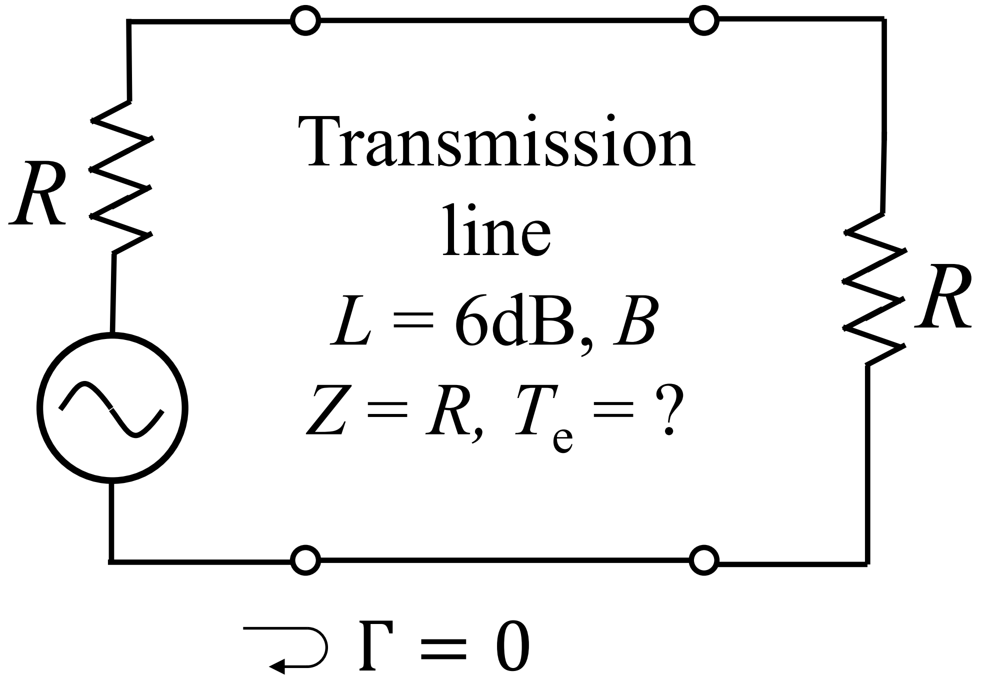
1. 225 K.
2. 300 K.
3. 600 K.
4. 900 K.
5. I do not know.

Room temperature

$T_{phy} = 300\text{K}$

$\log_{10} 2 = 0.30$,

$\log_{10} 3 = 0.47$



R

Transmission line

$L = 6\text{dB}, B$

$Z = R,\ T_e = ?$

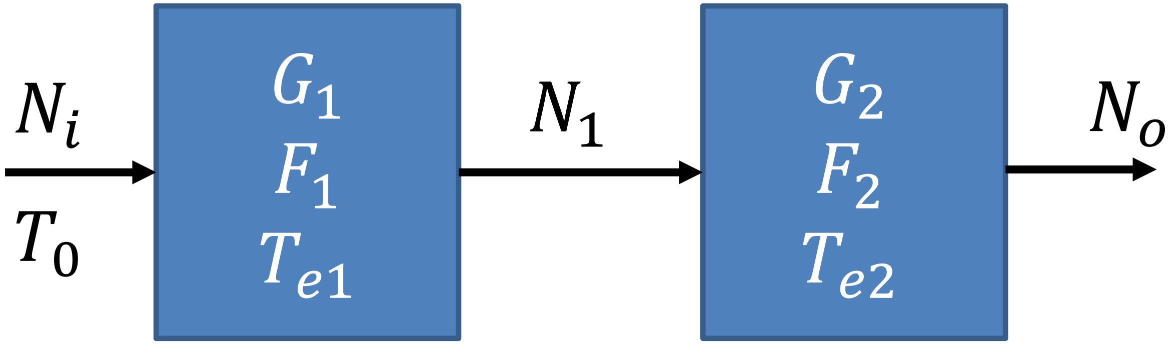
R

$\Gamma = 0$

Pozar Chapter 10.2

Noise temperature of receiver

- The first component at the RF front-end is most influential to total noise of the receiver.
  - We therefore use “low-noise” amplifier in the receiver.



$$T_{cas} = T_{e1} + \frac{T_{e2}}{G_1}$$

Pozar Chapter 10.2

Q6: There is a low noise amplifier of the following input, output and component parameters. Choose **an incorrect formula or explanation**. Choose 5. if you do not know what to choose.

Room temperature T_0 = 290 K

S_i: input signal power

N_i: input noise power

T_A = 150 K: input noise temperature

Low noise amplifier

T_e = 580 K: noise temperature

G_e = 20 dB gain

F_e = 4.77 dB noise figure

S_o: output signal power

N_o: output noise power

1. $(S_o / N_o) = (S_i / N_i) - F_e$ in dB.
2. $F_e = 1 + T_e / T_0$.
3. $N_o = kT_A BG_e + kT_e BG_e$.
4. (S_o / N_o) does not depend on G_e.
5. I do not know.

Pozar Example 10.2