CHAPTER 6

Frequency Modulation

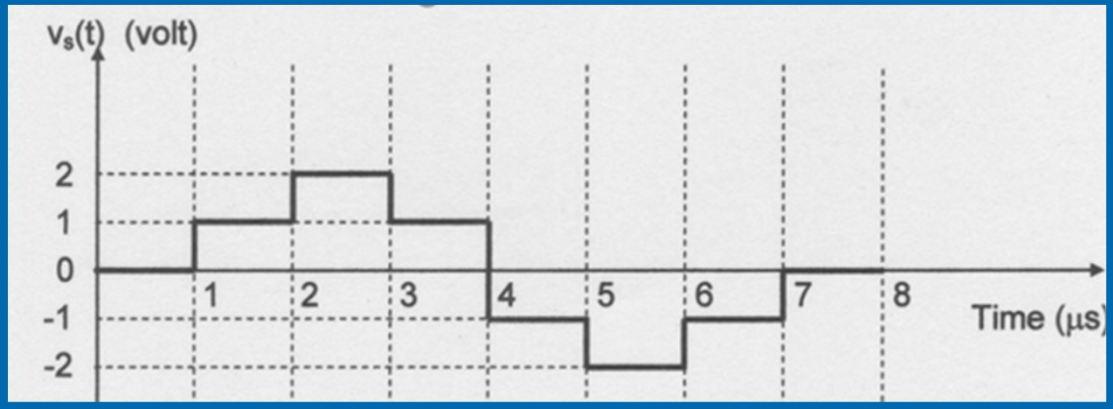
(Part 3 of 4)

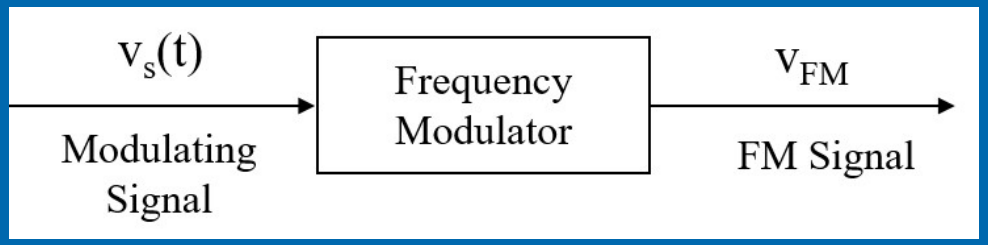
6.5 Multi-tone FM signal

Modulation of Multi-tone FM signal

Example 6.3

A carrier with frequency of 3 MHz is frequency modulated by a multi-tone modulating signal shown. The Conversion Gain, k_f =1 MHz/V . Plot the waveform of FM signal $v_{FM}(t)$ and the instantaneous frequency $f_i(t)$.





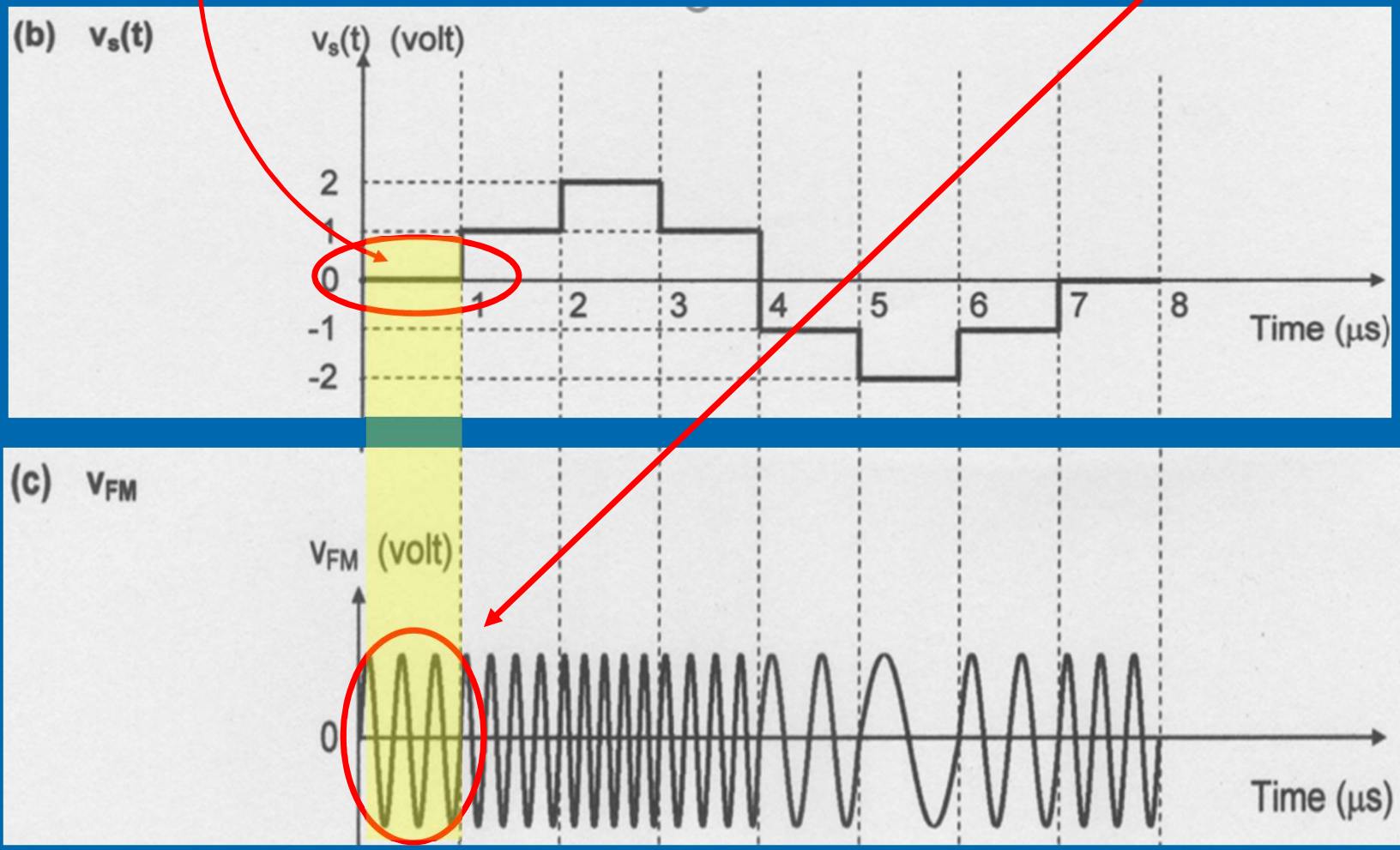
$v_s(t)$ → **Frequency Modulator** → v_{FM}

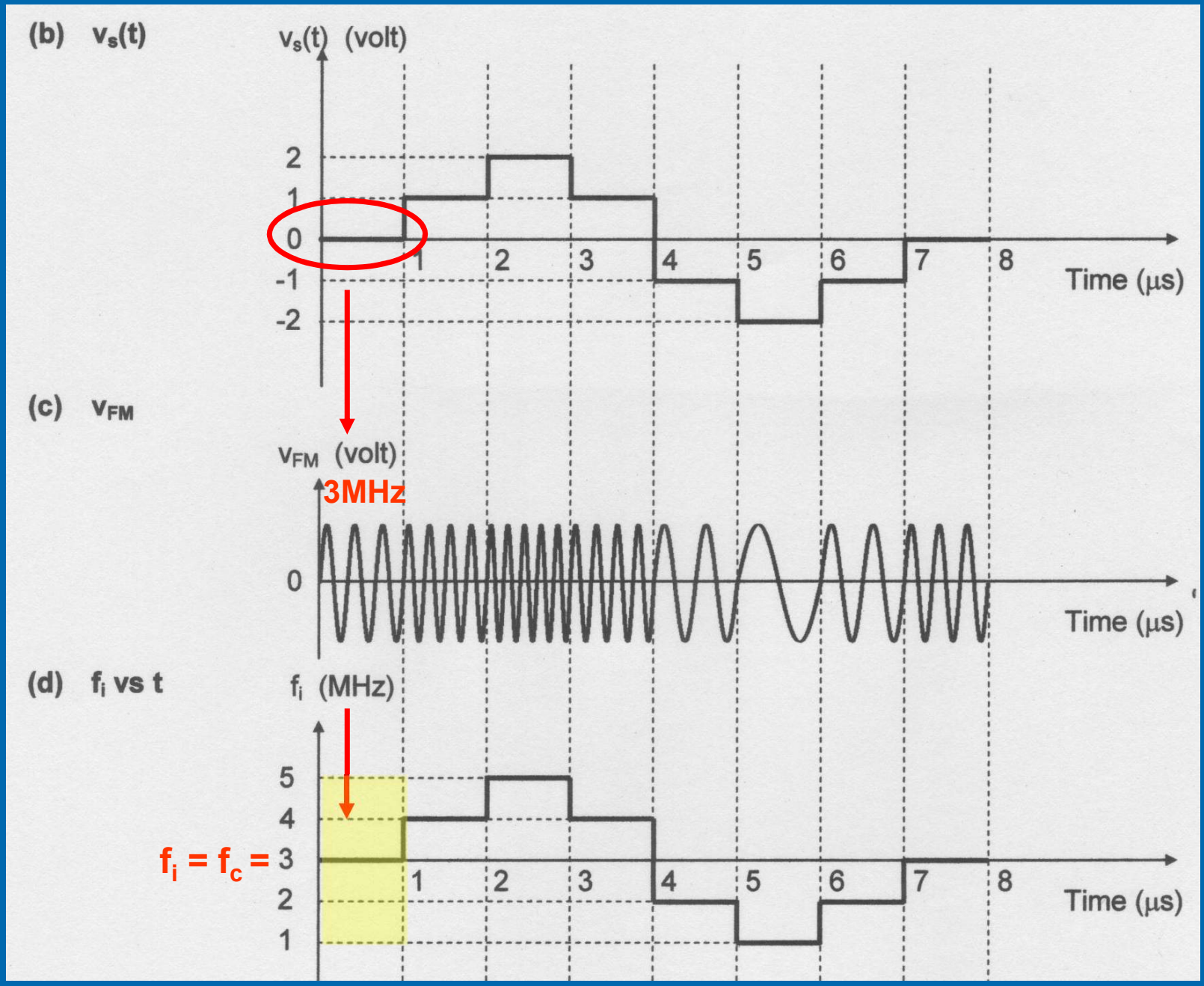
When $v_{s(t)}$ = 0V

k_f = 1 MHz/V

$f_i = f_c$ = 3MHz

f_c = 3MHz




(b) $v_s(t)$
$v_s(t)$ (volt)
2
1
0
-1
-2
1
2
3
4
5
6
7
8
Time (μs)
(c) v_{FM}
v_{FM} (volt)
3MHz
0
Time (μs)
(d) f_i vs t
f_i (MHz)
$f_i = f_c =$
5
4
3
2
1
1
2
3
4
5
6
7
8
Time (μs)

$v_s(t)$ → **Frequency Modulator** → v_{FM}

When $v_{s(t)} = V_s$

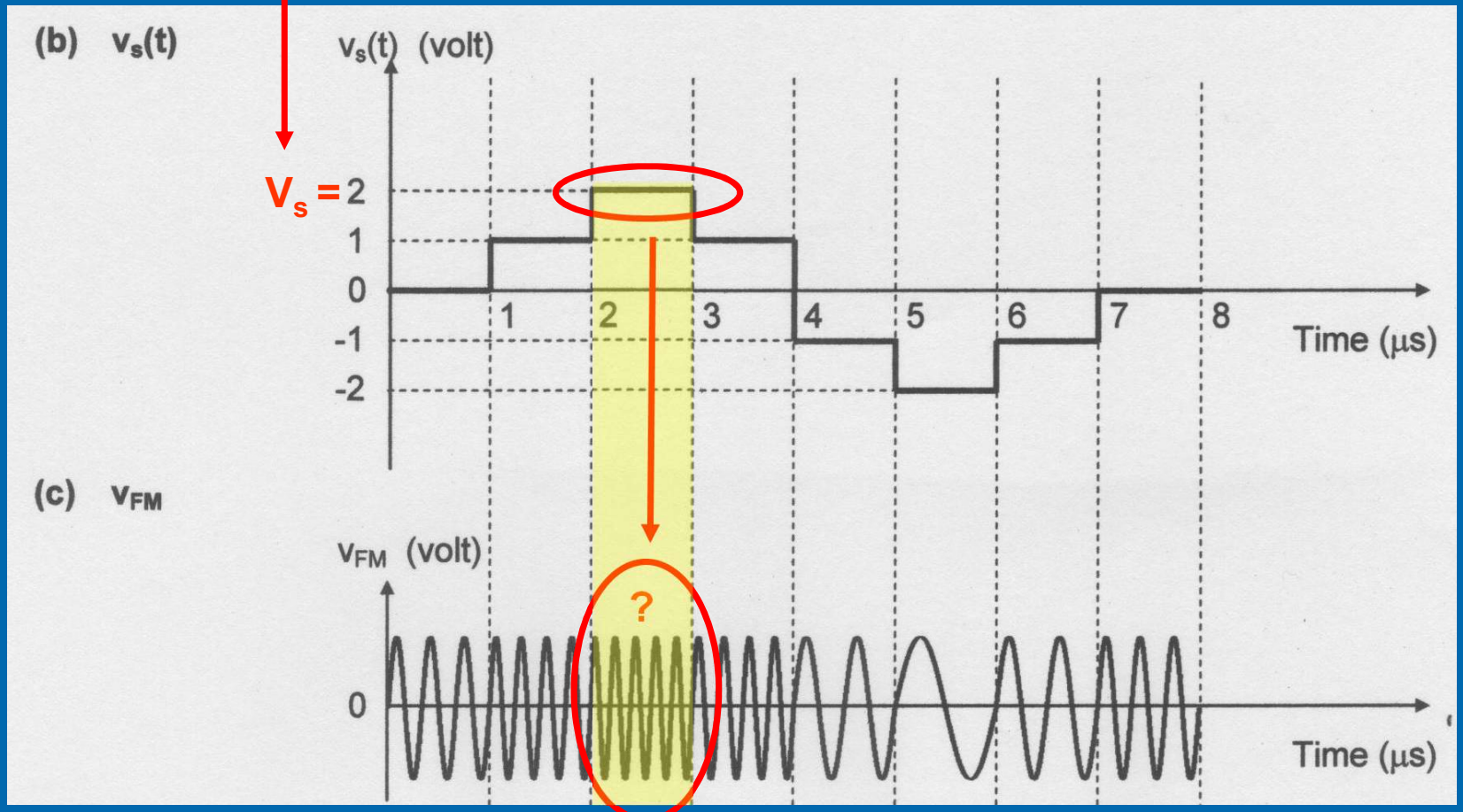
$k_f = 1$ MHz/V

$f_c = 3$MHz

$f_i = f_{i(max)}$

$\Delta_f = k_f V_s$

$f_{i(max)} = f_c + \Delta_f$



$v_s(t)$ → **Frequency Modulator** → v_{FM}

When $v_s(t) = V_s$

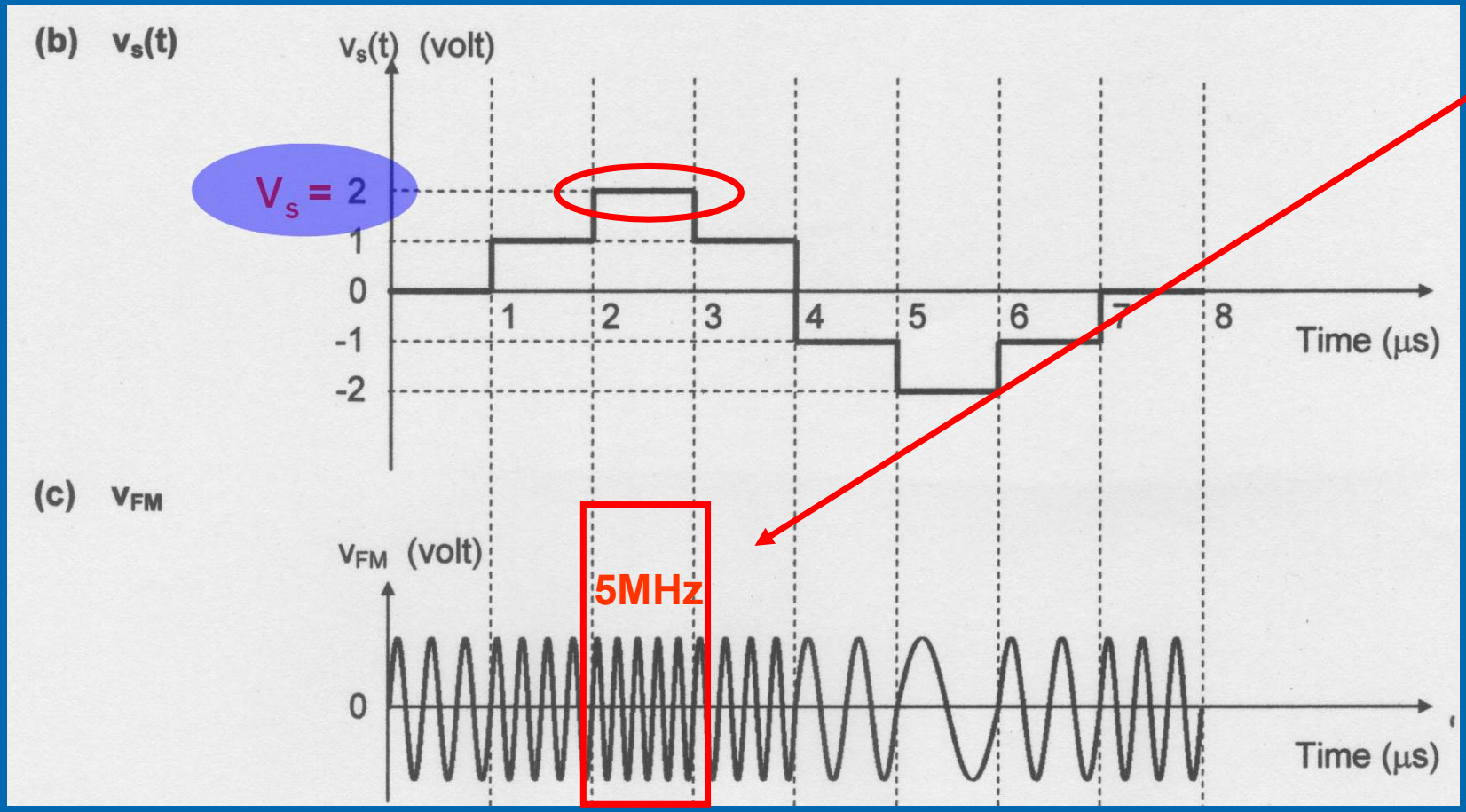
$k_f = 1$ MHz/V

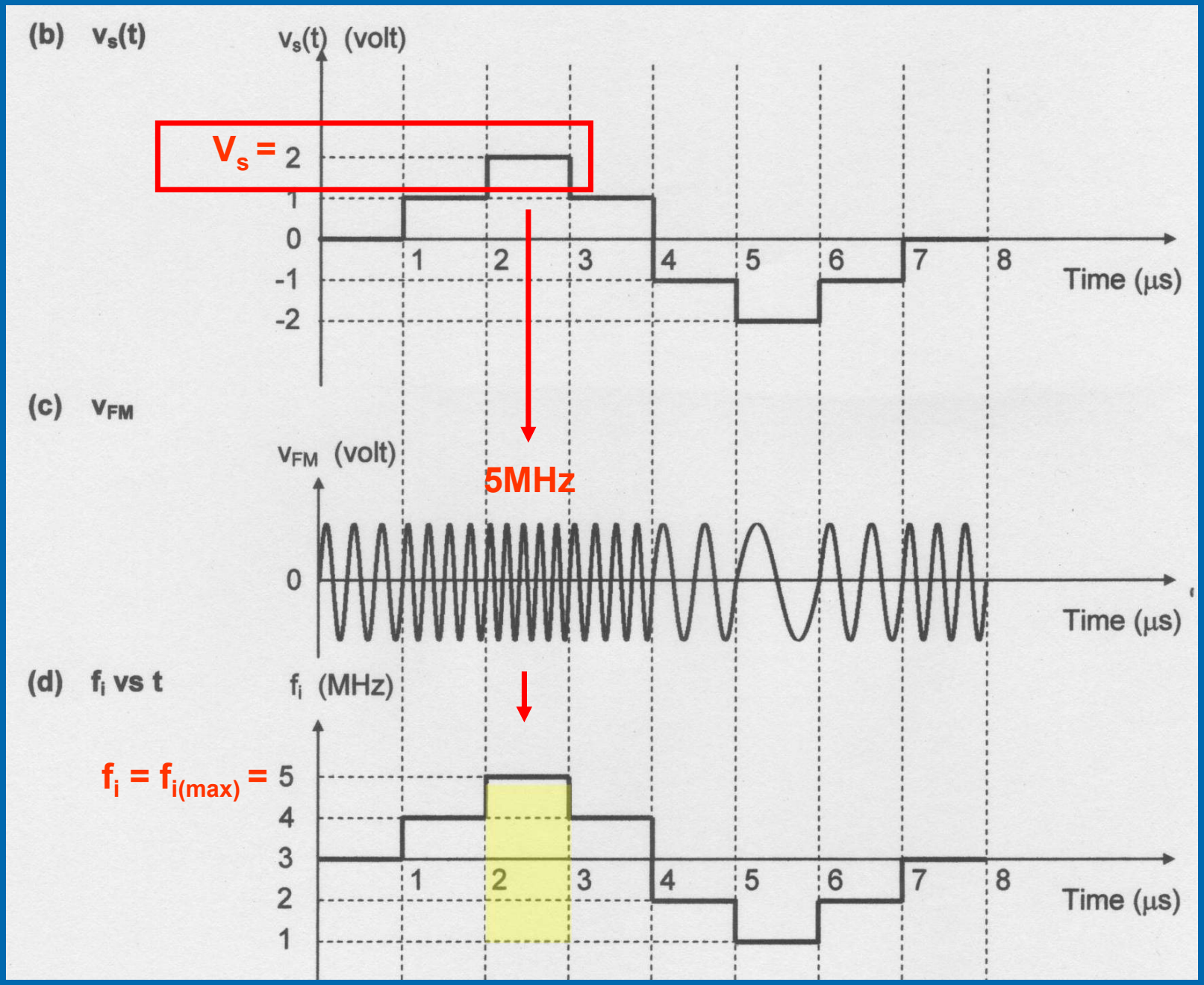
$f_c = 3$MHz

$f_i = f_{i(max)}$

$\Delta_f = k_f V_s = 1\text{MHz/V} \times 2\text{V} = 2\text{MHz}$

$f_{i(max)} = f_c + \Delta_f = 3 + 2 = 5\text{MHz}$




(b) $v_s(t)$
$v_s(t)$ (volt)
V_s = 2
1
0
-1
-2
1 2 3 4 5 6 7 8
Time (μs)
(c) v_{FM}
v_{FM} (volt)
5MHz
0
Time (μs)
(d) f_i vs t
f_i (MHz)
$f_i = f_{i(max)}$ = 5
4
3
2
1
1 2 3 4 5 6 7 8
Time (μs)

$v_s(t)$ → **Frequency Modulator** → v_{FM}

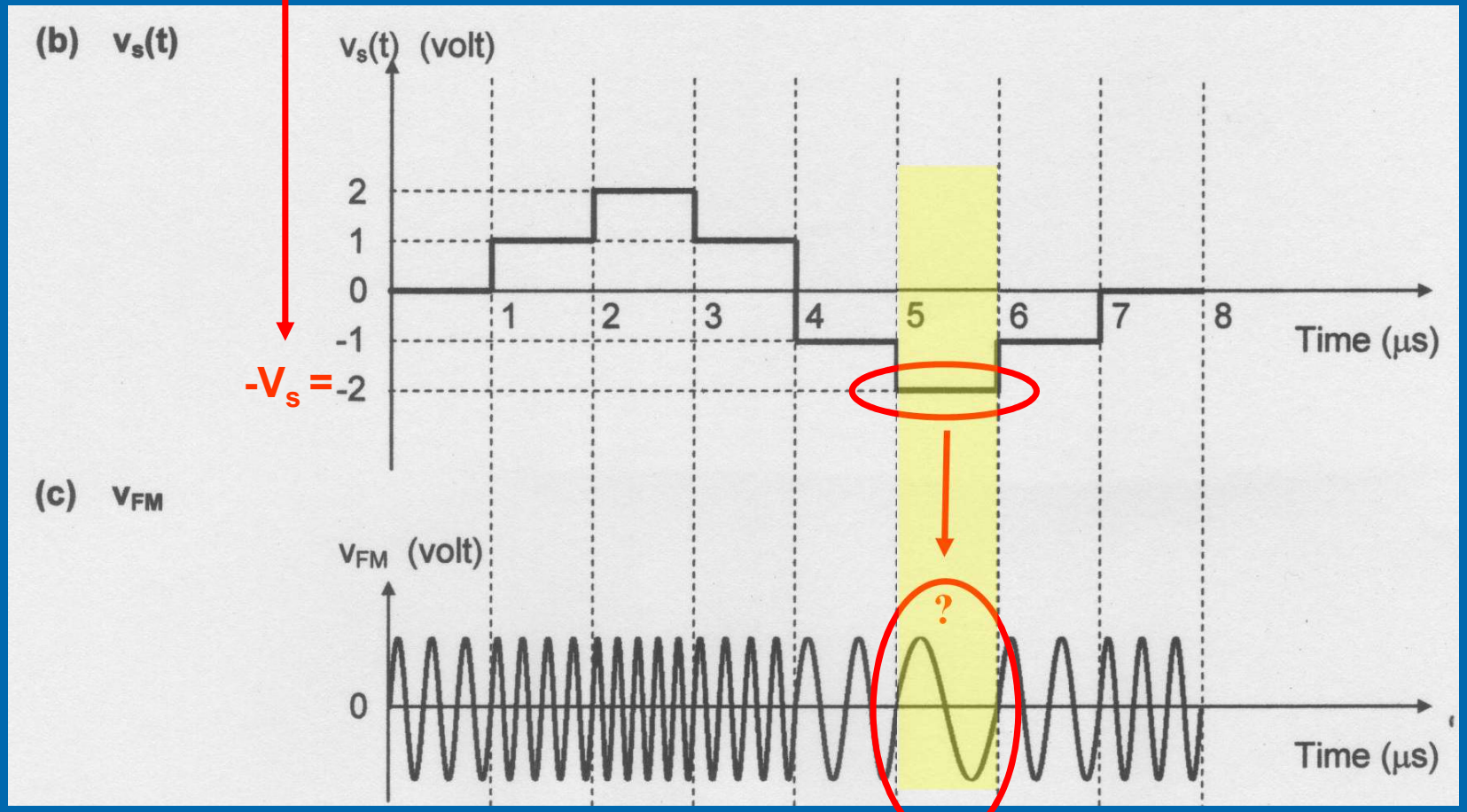
When $v_{s(t)} = -V_s$

$k_f = 1$ MHz/V

$f_c = 3$MHz

$f_i = f_{i(min)}$

$f_{i(min)} = f_c - \Delta_f$



$v_s(t)$ → **Frequency Modulator** → v_{FM}

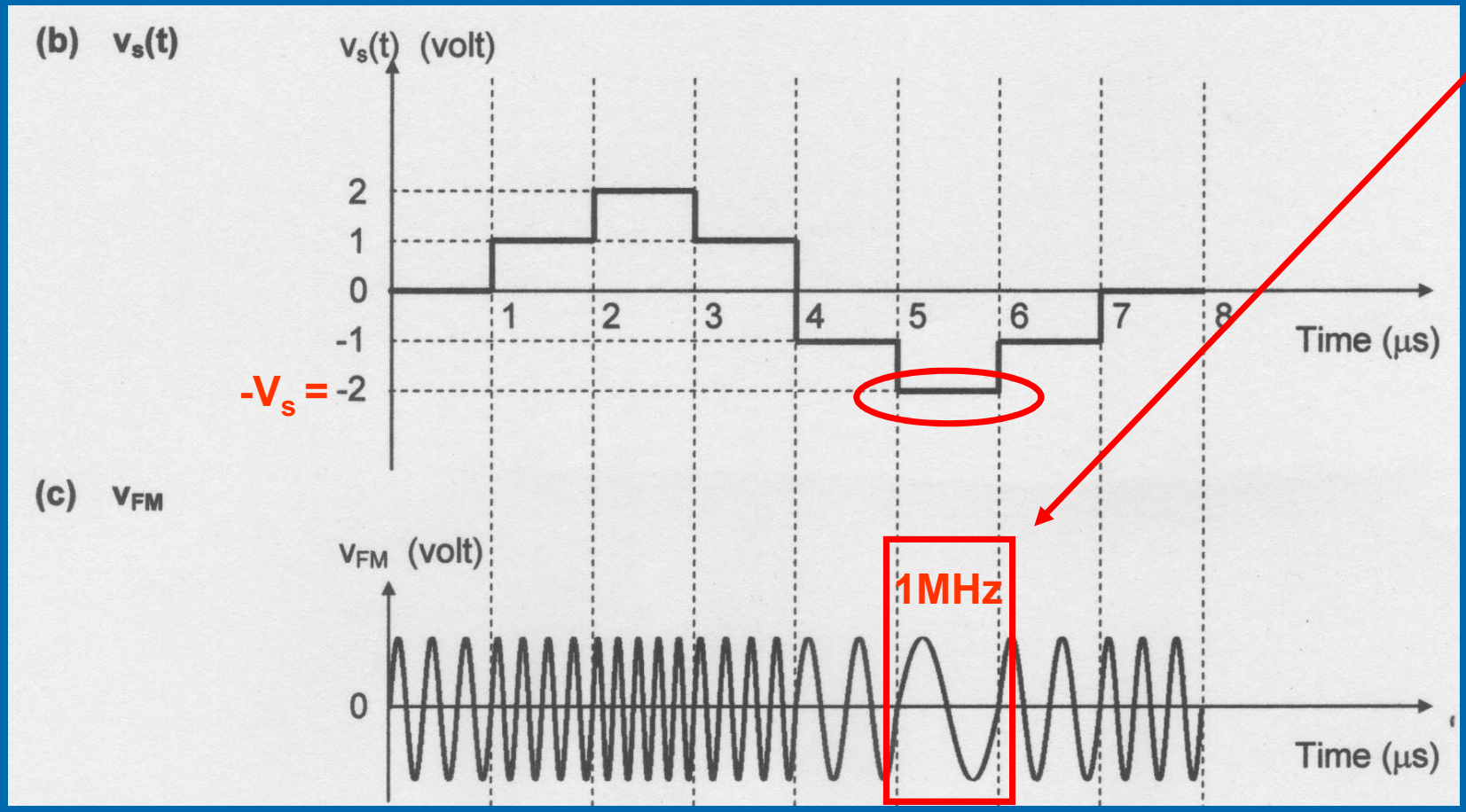
When $v_{s(t)} = -V_s$

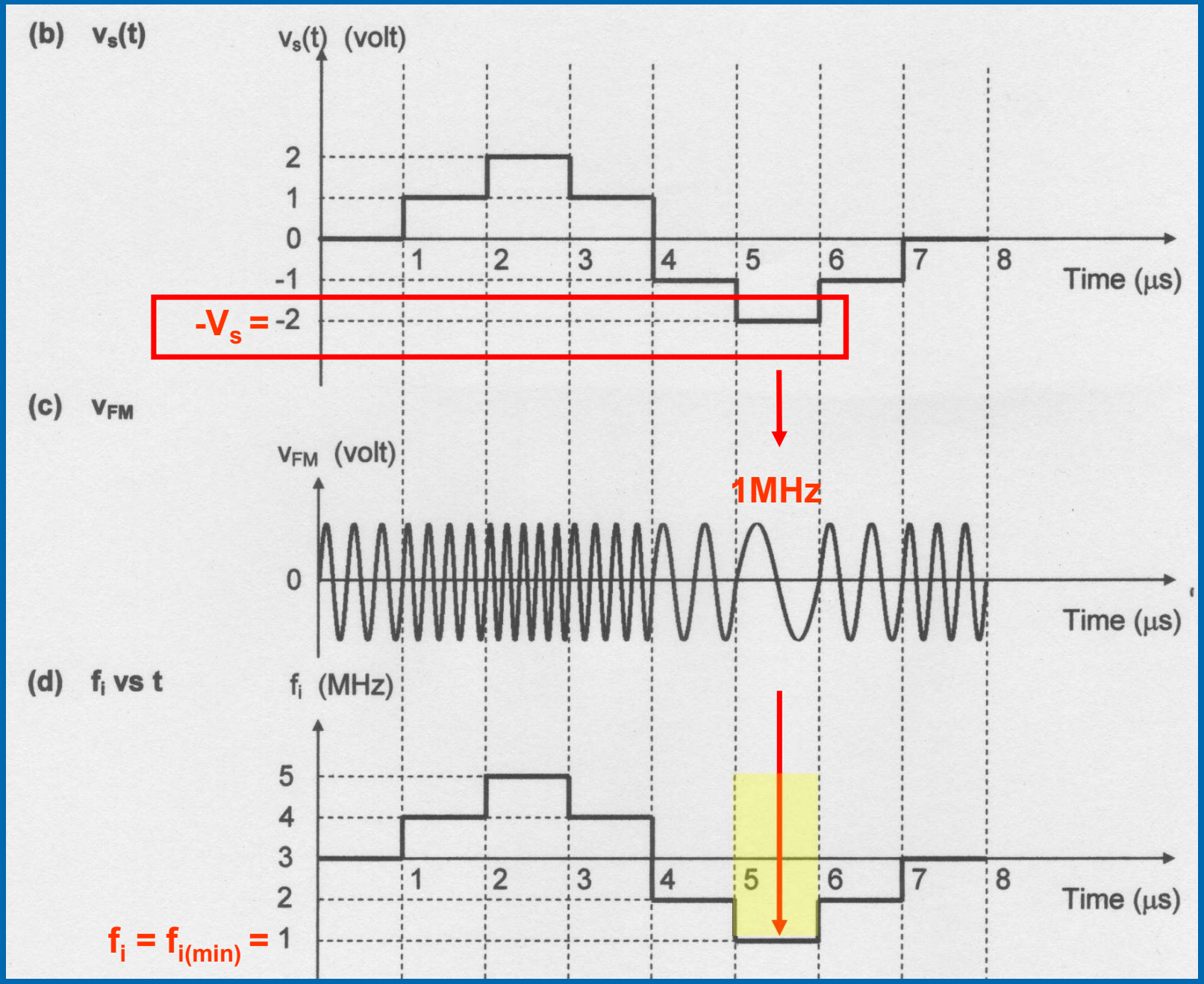
$k_f = 1$ MHz/V

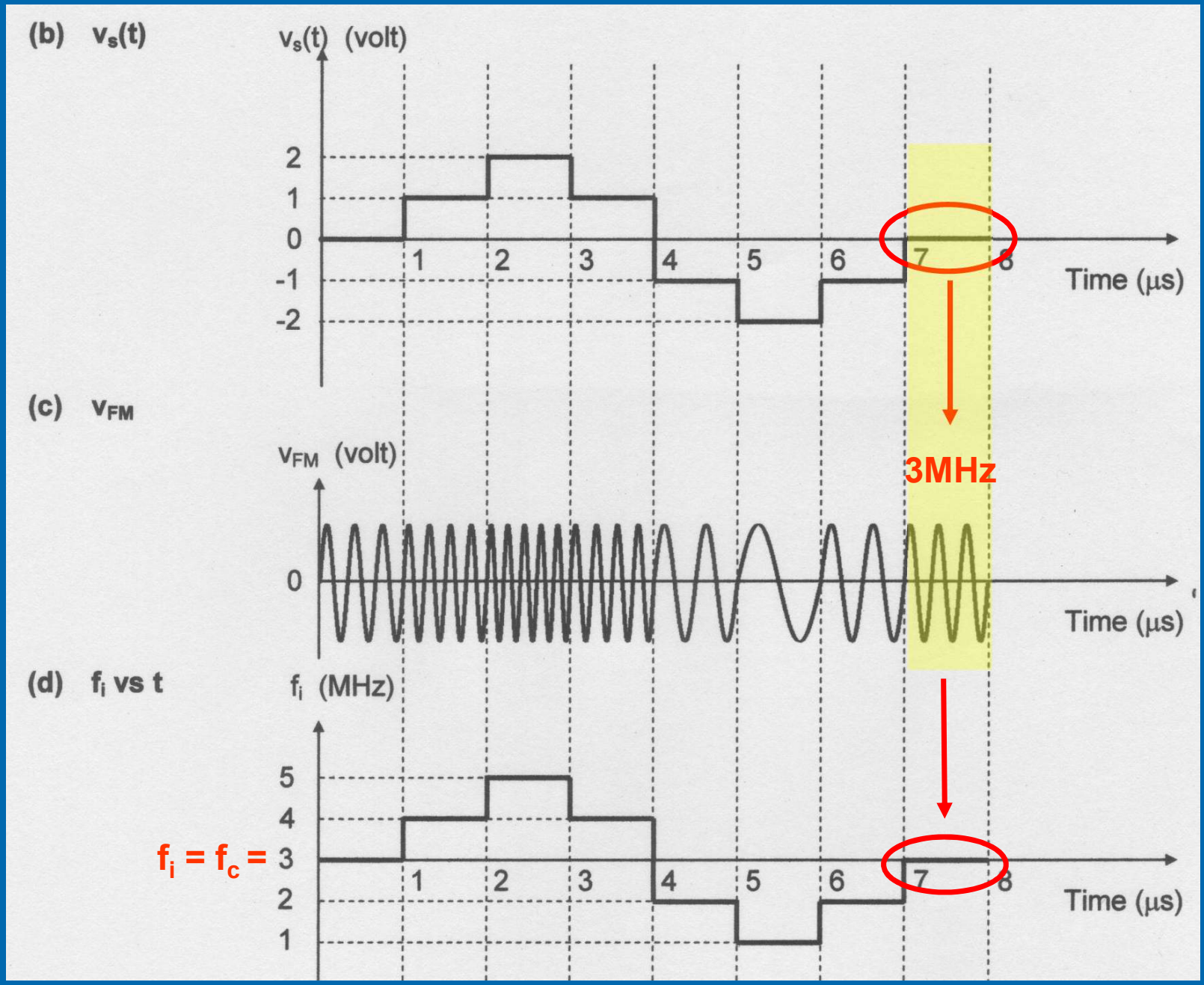
$f_c = 3$MHz

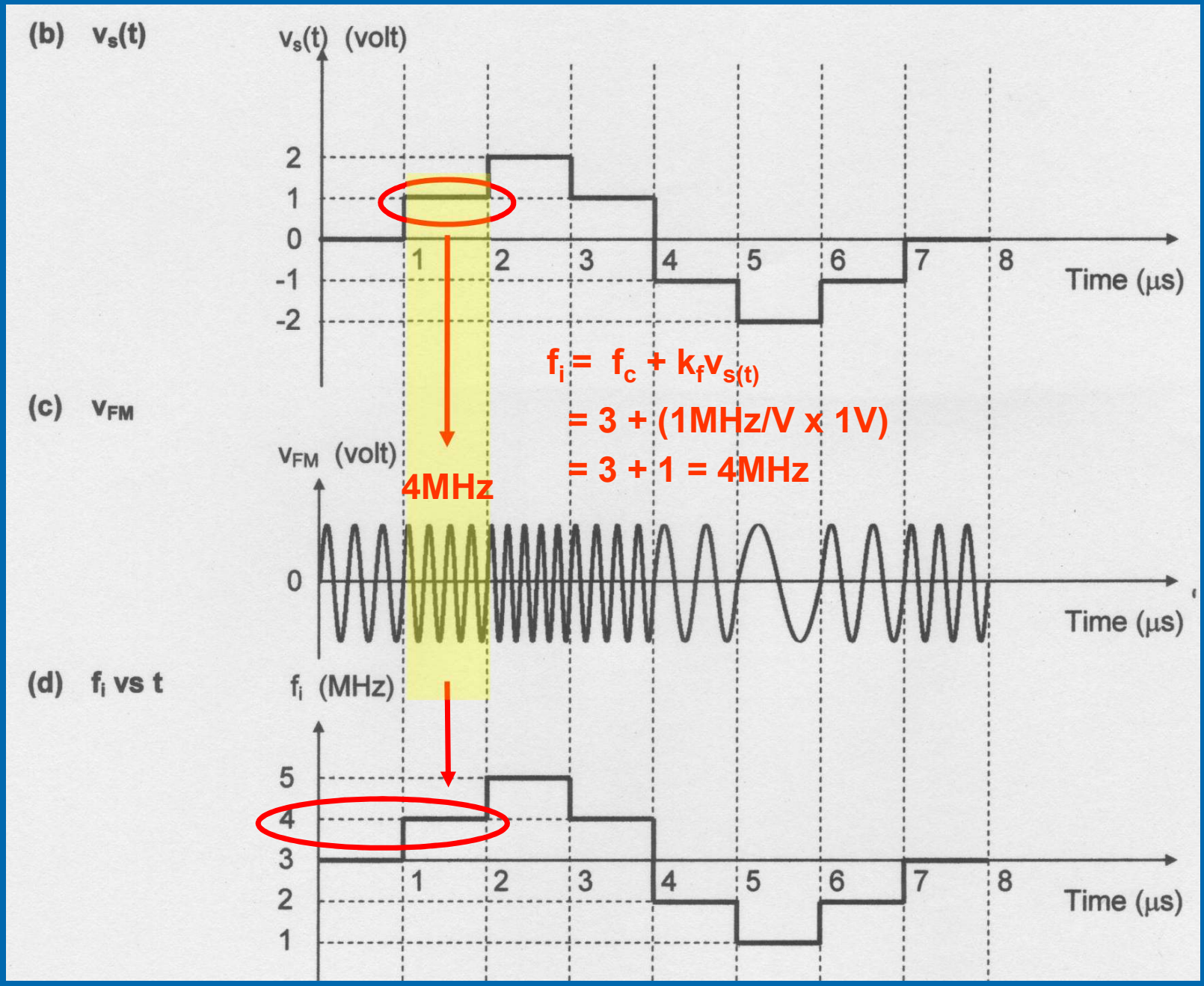
$f_i = f_{i(min)}$

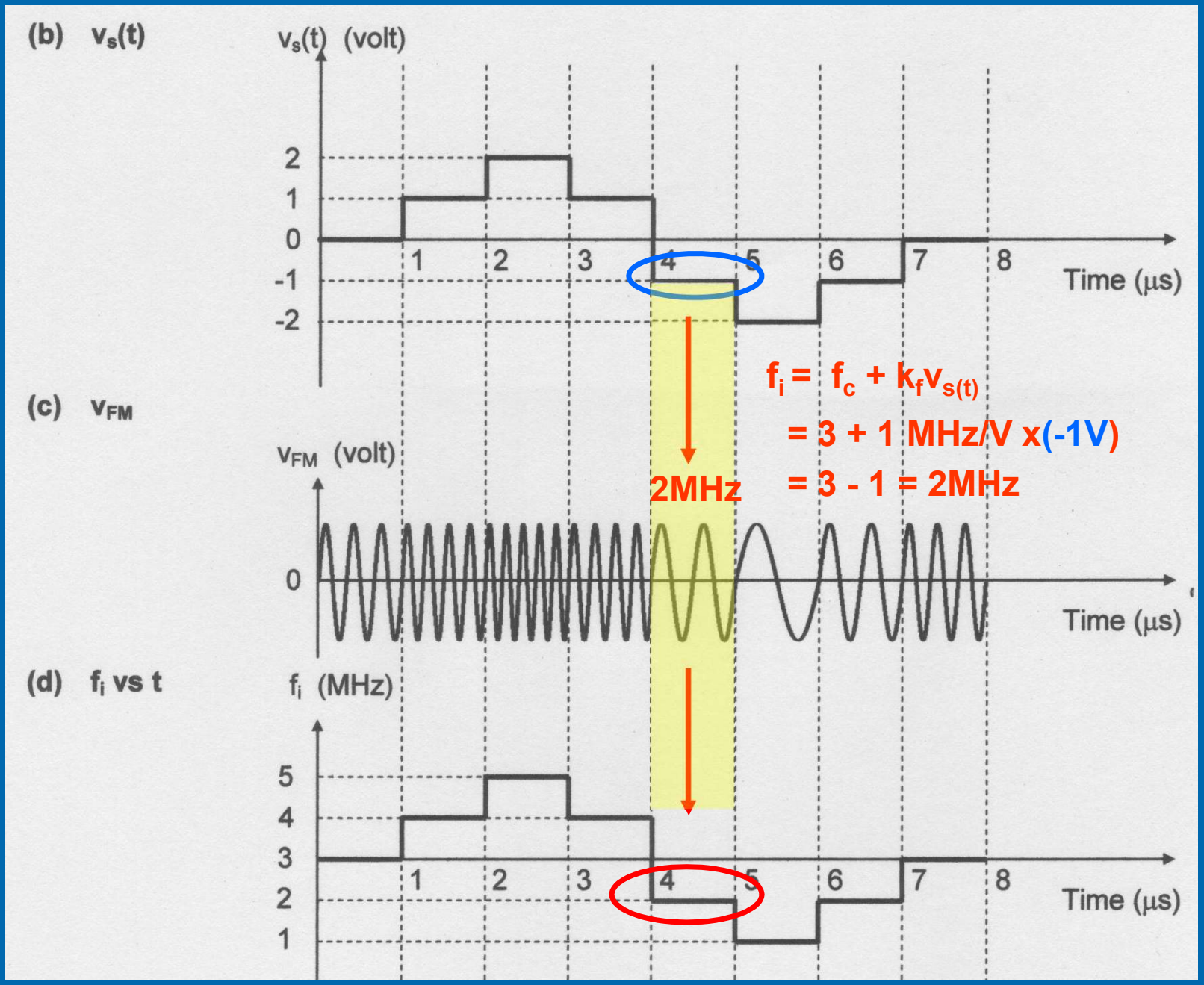
$f_{i(max)} = f_c - \Delta_f = 3 - 2 = 1$MHz

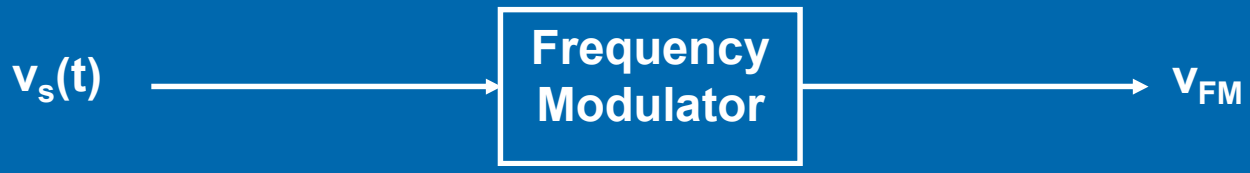



(b) $v_s(t)$
$v_s(t)$ (volt)
2
1
0
-1
-2
$-V_s$ =
1
2
3
4
5
6
7
8
Time (μs)
(c) v_{FM}
v_{FM} (volt)
1MHz
0
Time (μs)
(d) f_i vs t
f_i (MHz)
5
4
3
2
1
$f_i = f_{i(min)}$ =
1
2
3
4
5
6
7
8
Time (μs)

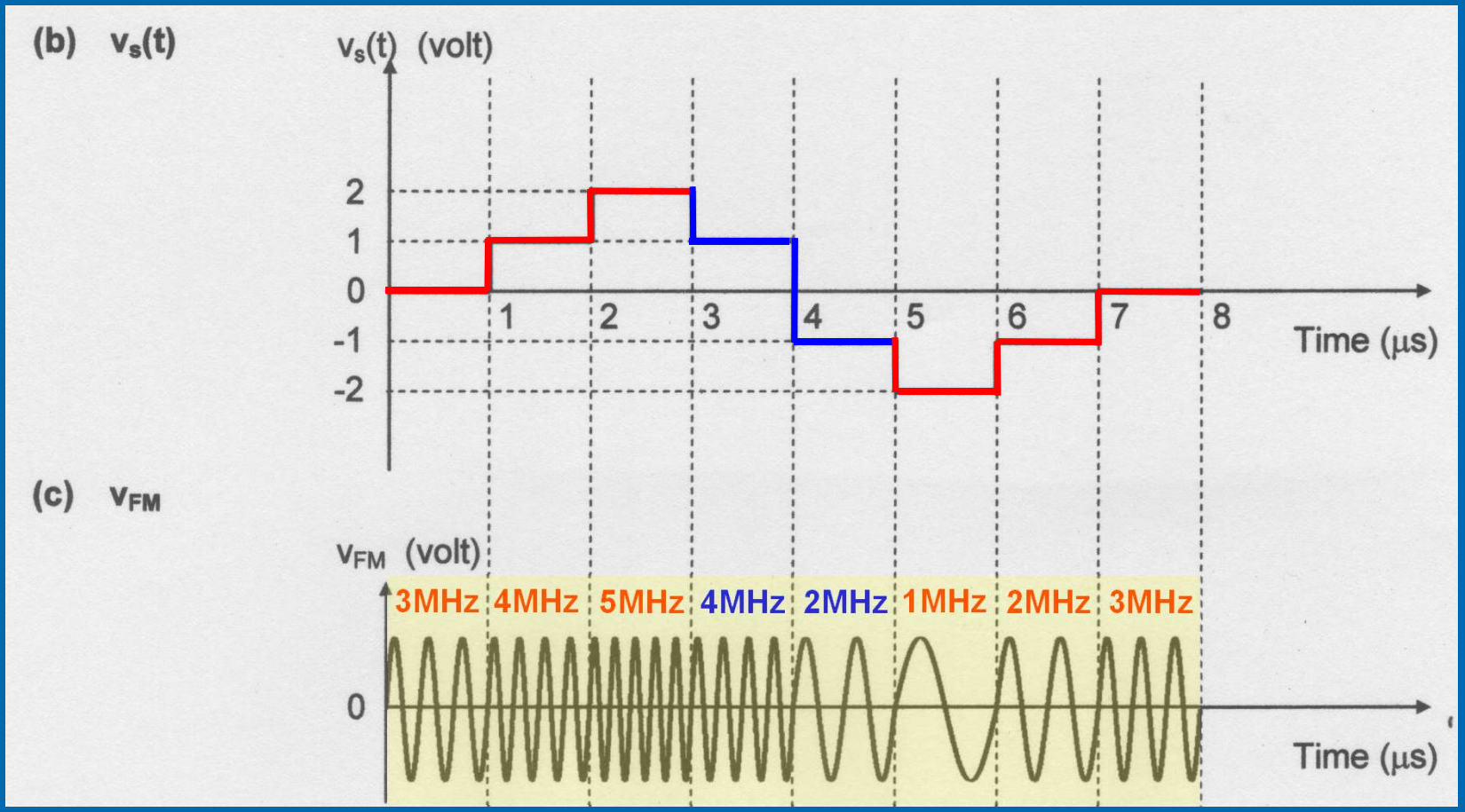

(b) $v_s(t)$
$v_s(t)$ (volt)
2
1
0
-1
-2
1
2
3
4
5
6
7
8
Time (μs)
(c) v_{FM}
v_{FM} (volt)
3MHz
0
Time (μs)
(d) f_i vs t
f_i (MHz)
$f_i = f_c =$
5
4
3
2
1
1
2
3
4
5
6
7
8
Time (μs)

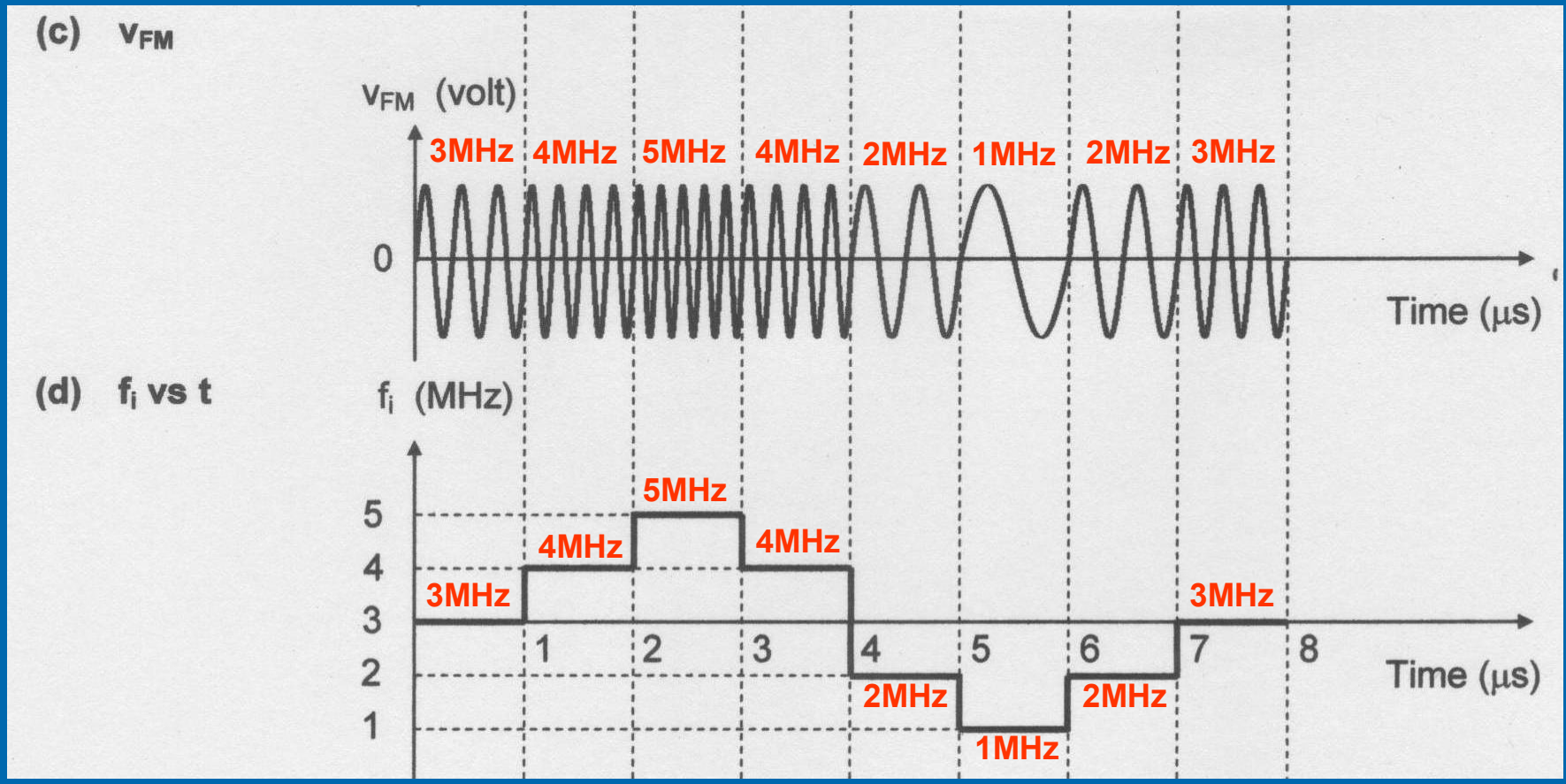

(b) $v_s(t)$
$v_s(t)$ (volt)
2
1
0
-1
-2
1
2
3
4
5
6
7
8
Time (μs)
$f_i = f_c + k_f v_{s(t)}$
$= 3 + (1MHz/V \times 1V)$
$= 3 + 1 = 4MHz$
(c) v_{FM}
v_{FM} (volt)
4MHz
0
Time (μs)
(d) f_i vs t
f_i (MHz)
5
4
3
2
1
1
2
3
4
5
6
7
8
Time (μs)


(b) $v_s(t)$
$v_s(t)$ (volt)
2
1
0
-1
-2
1
2
3
4
5
6
7
8
Time (μs)
$f_i = f_c + k_f v_{s(t)}$
$= 3 + 1\ MHz/V \times (-1V)$
$= 3 - 1 = 2MHz$
2MHz
(c) v_{FM}
v_{FM} (volt)
0
Time (μs)
(d) f_i vs t
f_i (MHz)
5
4
3
2
1
1
2
3
4
5
6
7
8
Time (μs)

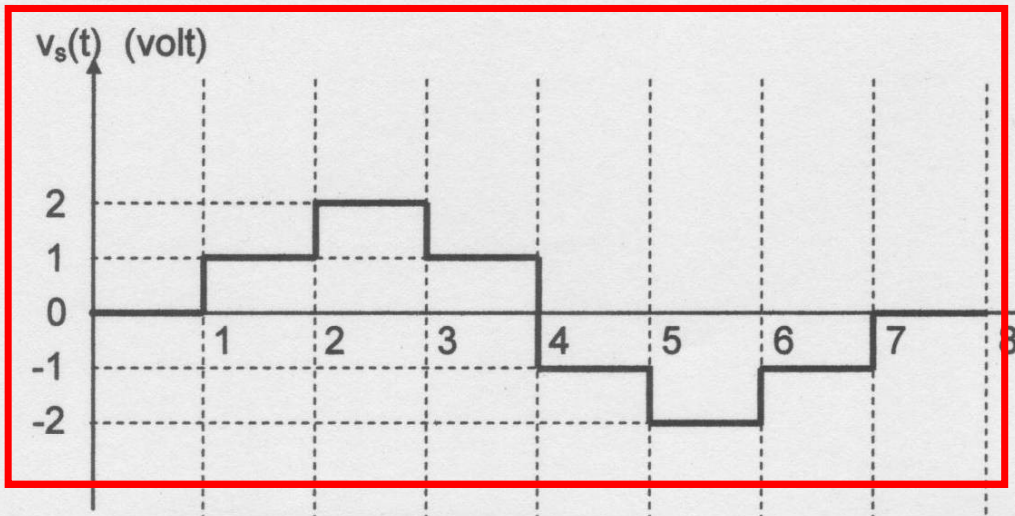


Converts voltage change to frequency change

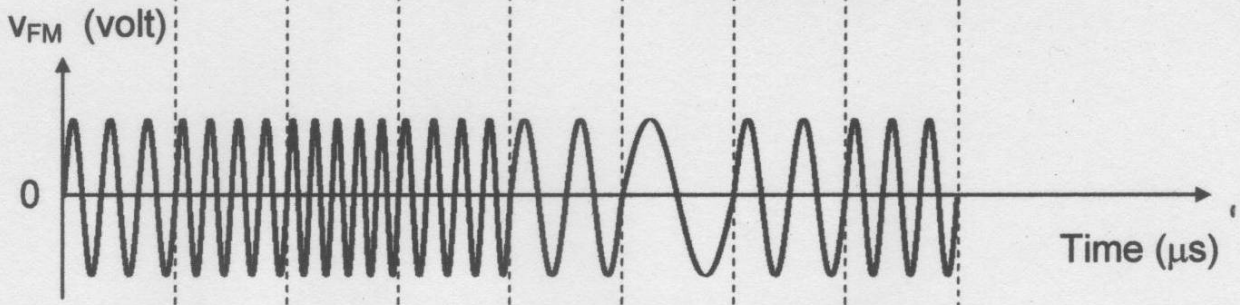



(c) v_{FM}
v_{FM} (volt)
3MHz
4MHz
5MHz
4MHz
2MHz
1MHz
2MHz
3MHz
0
Time (μs)
(d) f_i vs t
f_i (MHz)
5
4
3
2
1
5MHz
4MHz
4MHz
3MHz
3MHz
2MHz
2MHz
1MHz
1
2
3
4
5
6
7
8
Time (μs)

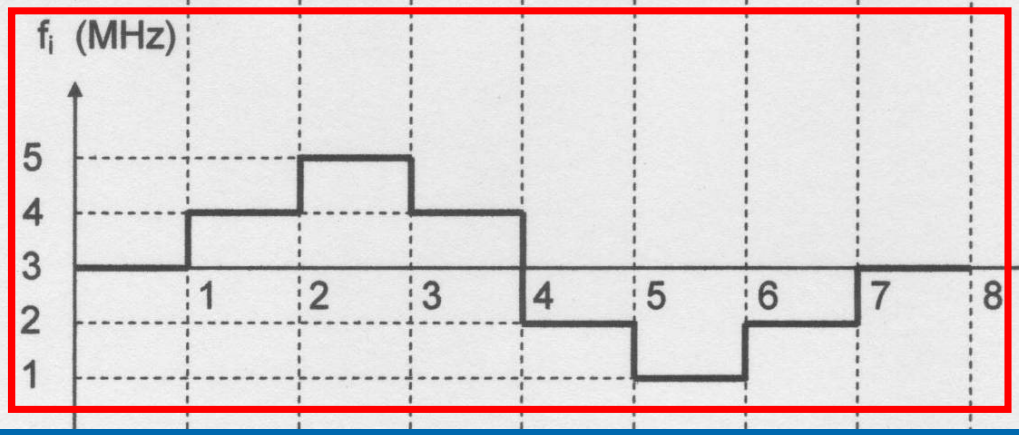
(b) $v_s(t)$



(c) v_{FM}



(d) f_i vs t



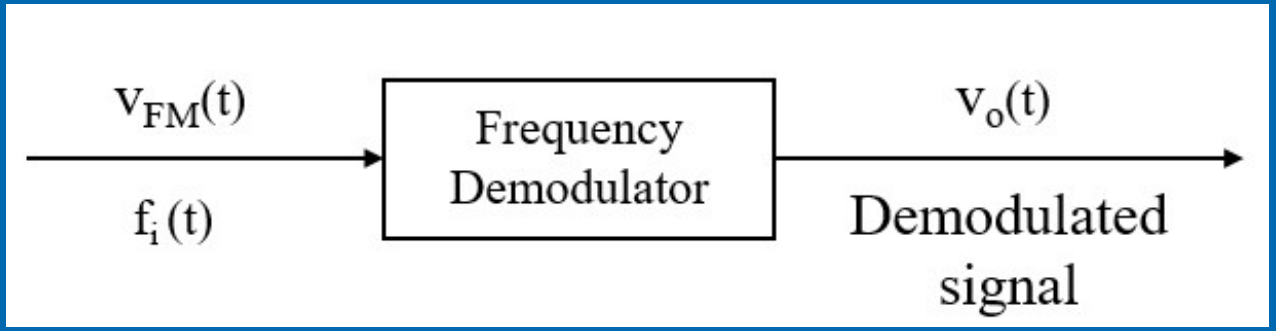
f_i changes the same way as $v_s(t)$.

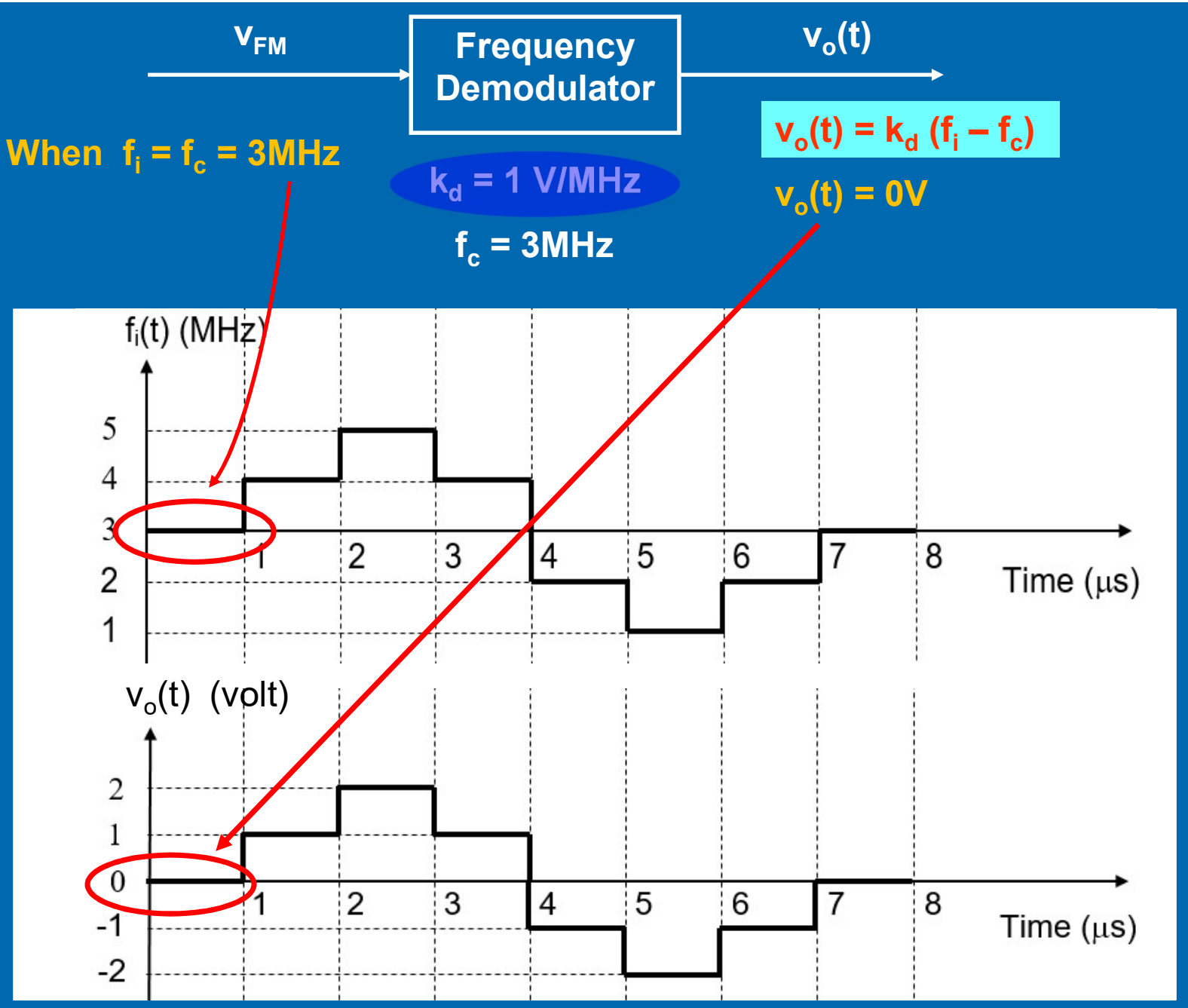
6.5 Multi-tone FM signal

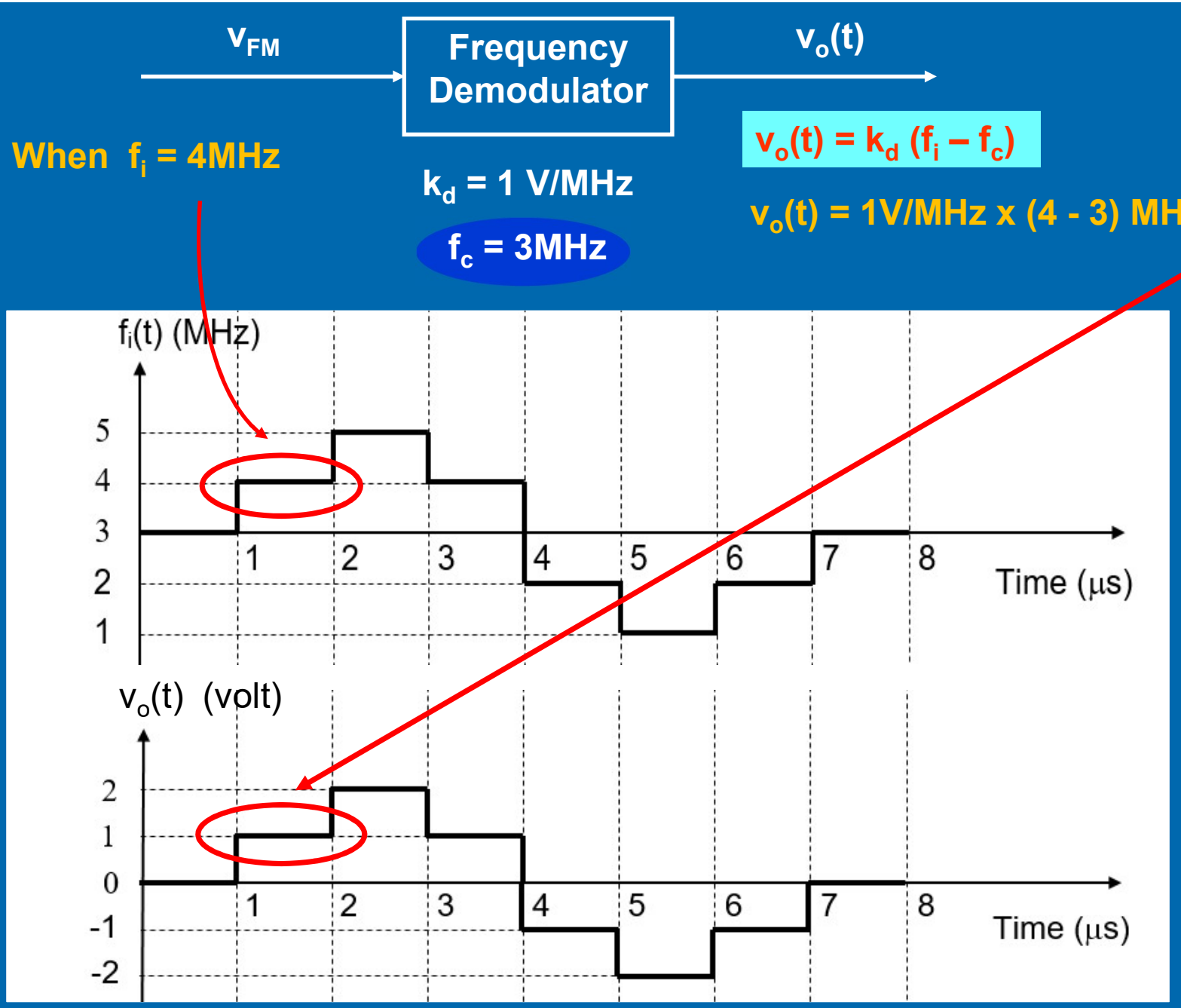
Demodulation of Multi-tone FM signal

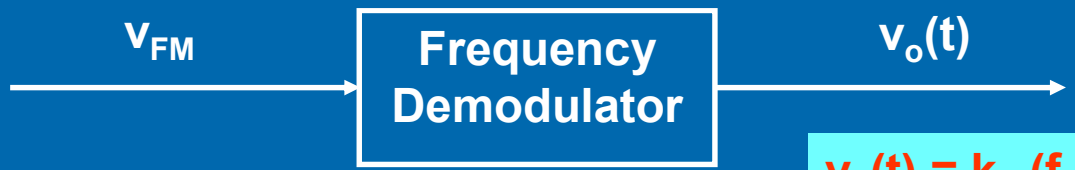
Example 6.4

At FM demodulator, the modulating signal is recovered by converting the frequency variation to a corresponding voltage variation. The conversion gain, k_d = 1 V/MHz. Plot the recovered modulating signal if the input signal of FM demodulator is the FM signal from example 6.3.




V_{FM}
Frequency Demodulator
$v_o(t)$
When $f_i = f_c = 3MHz$
$k_d = 1$ V/MHz
$f_c = 3MHz$
$v_o(t) = k_d (f_i - f_c)$
$v_o(t) = 0V$
$f_i(t)$ (MHz)
5
4
3
2
1
1
2
3
4
5
6
7
8
Time (μs)
$v_o(t)$ (volt)
2
1
0
-1
-2
1
2
3
4
5
6
7
8
Time (μs)


V_{FM}
Frequency Demodulator
$v_o(t)$
When f_i = 4MHz
k_d = 1 V/MHz
f_c = 3MHz
$v_o(t) = k_d (f_i - f_c)$
$v_o(t)$ = 1V/MHz x (4 - 3) MHz = 1V
$f_i(t)$ (MHz)
5
4
3
2
1
1
2
3
4
5
6
7
8
Time (μs)
$v_o(t)$ (volt)
2
1
0
-1
-2
1
2
3
4
5
6
7
8
Time (μs)



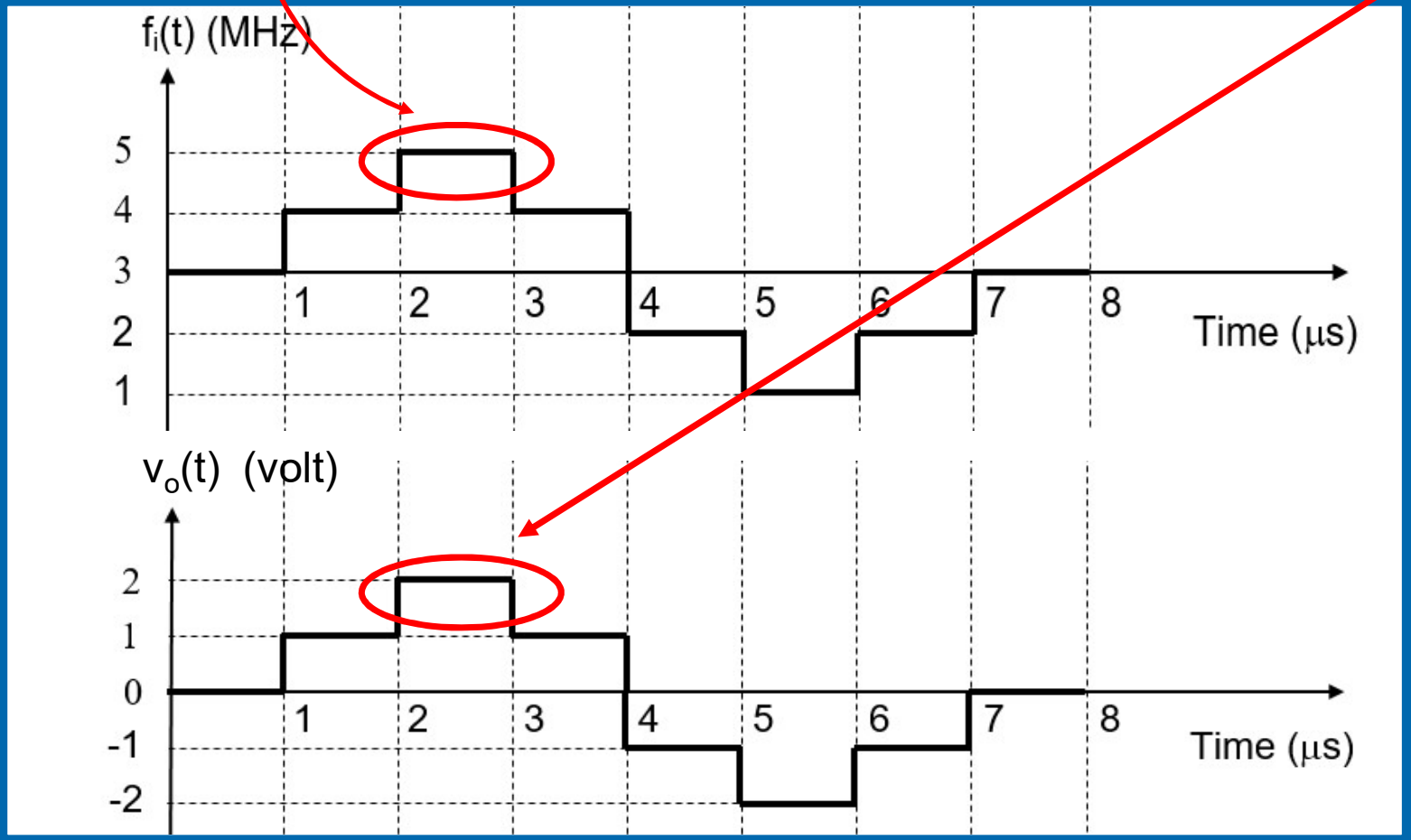
When $f_i = 5MHz$

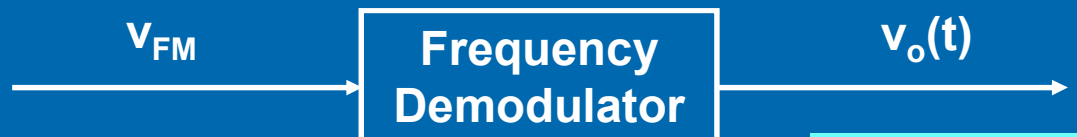
$k_d = 1$ V/MHz

$f_c = 3MHz$

$v_o(t) = k_d (f_i - f_c)$

$v_o(t) = 1V/MHz \times (5 - 3)\ MHz = 2V$





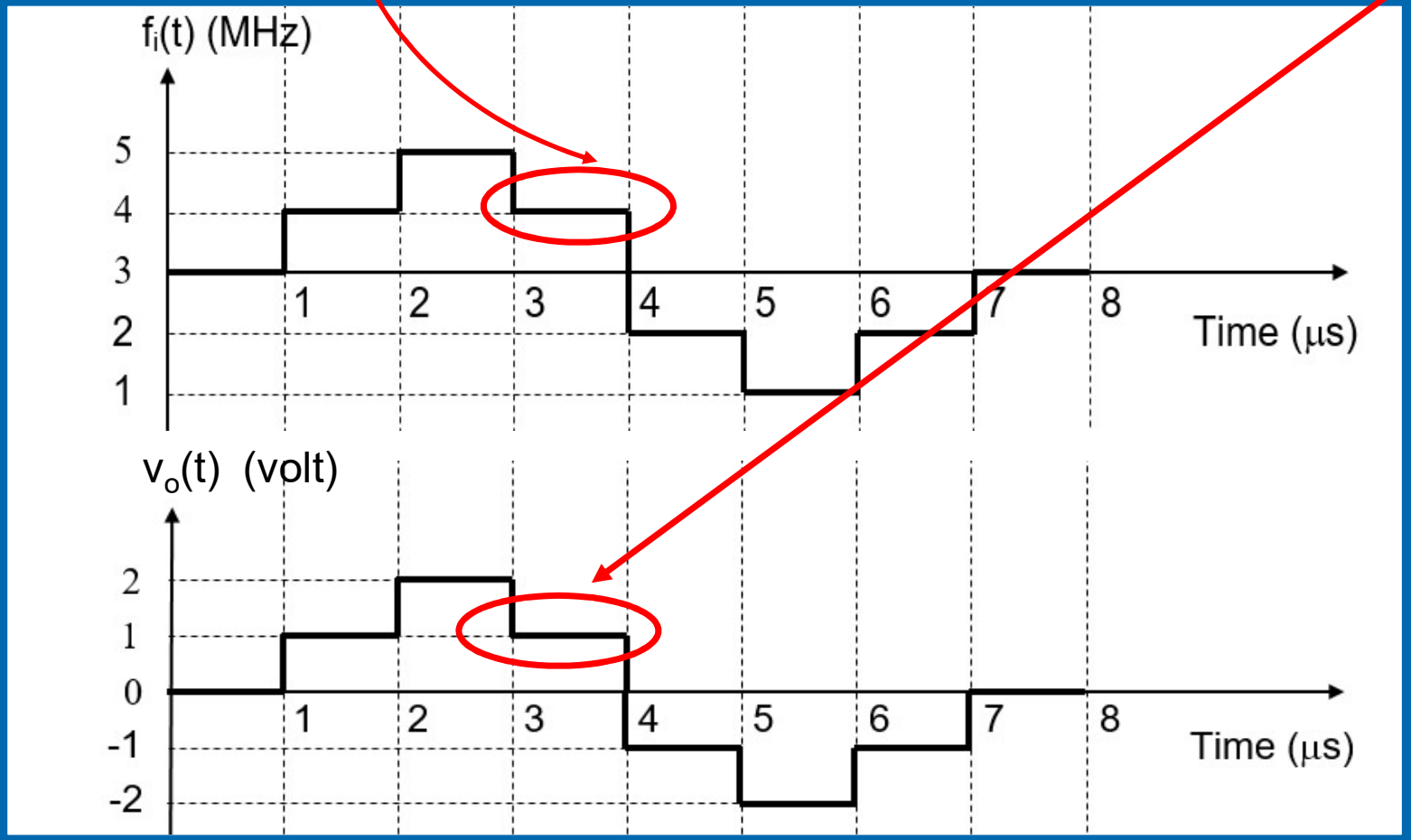
When $f_i = f_c = 4$ MHz

$k_d = 1$ V/MHz

$f_c = 3$MHz

$v_o(t) = k_d (f_i - f_c)$

$v_o(t) = 1V/MHz \times (4 - 3)$ MHz $= 1$ V



V_{FM} → **Frequency Demodulator** → $v_o(t)$

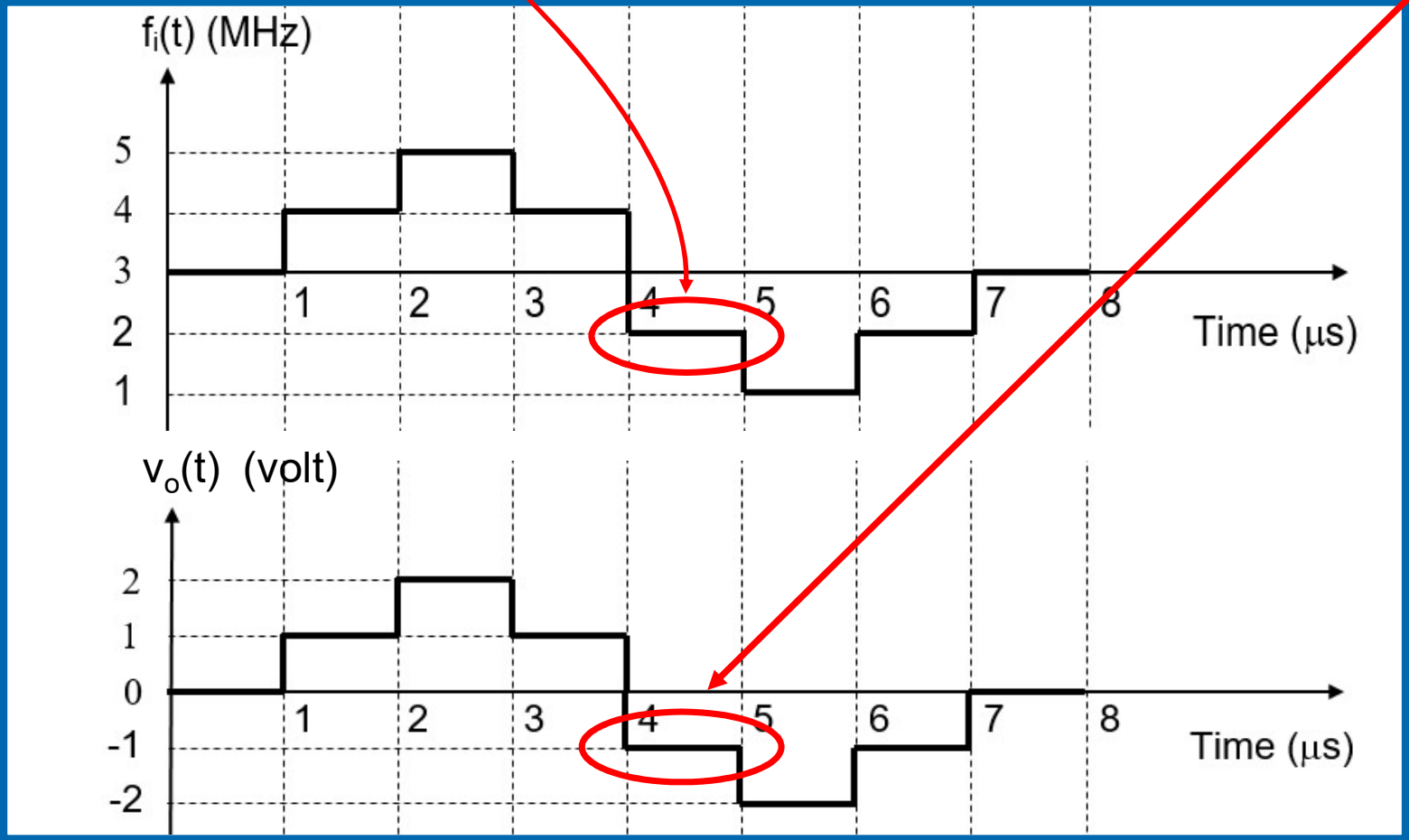
When $f_i = 2$ MHz

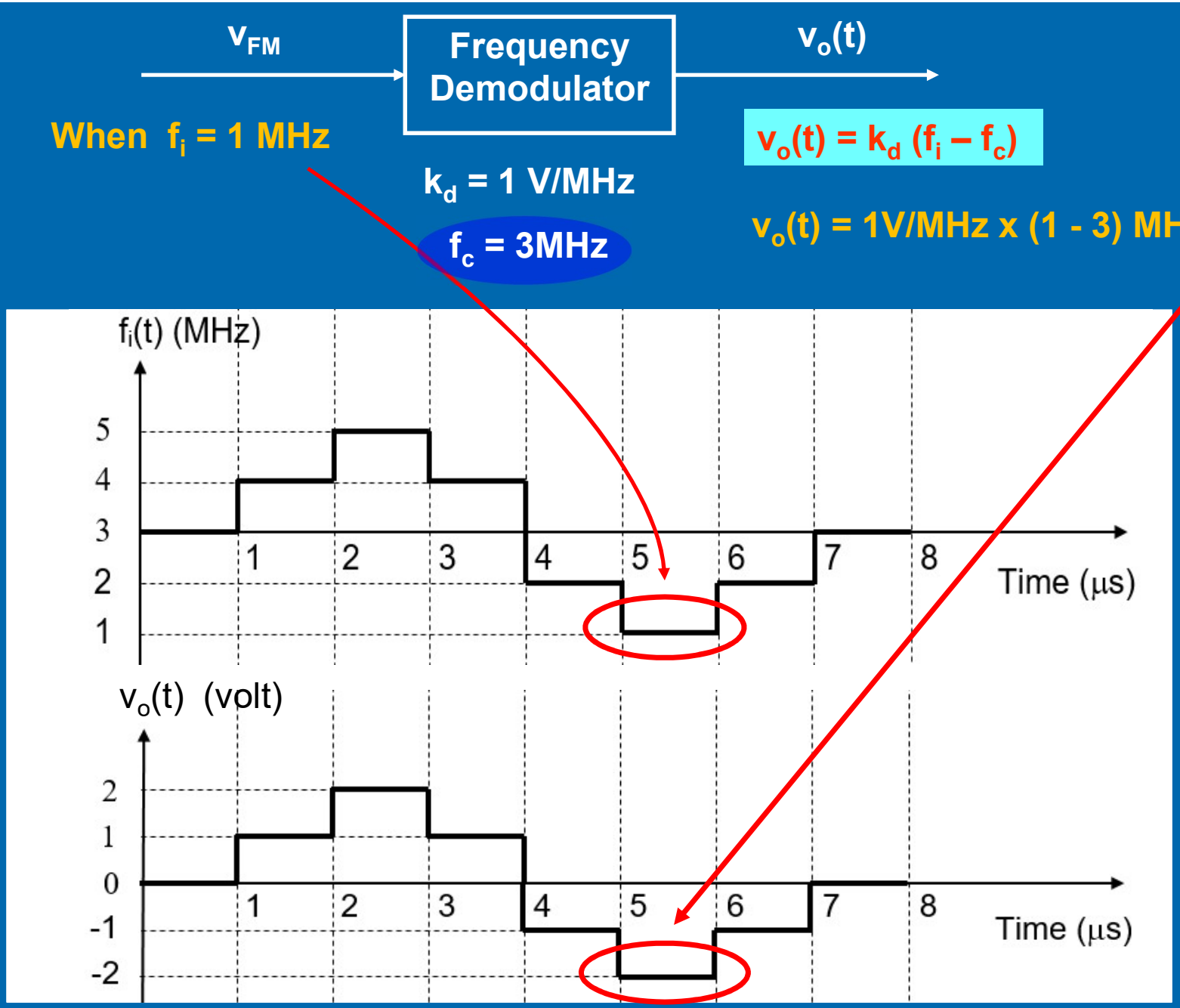
$k_d = 1$ V/MHz

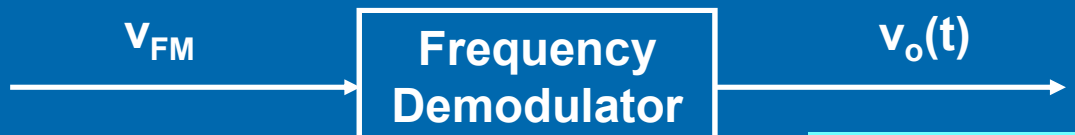
$f_c = 3$MHz

$v_o(t) = k_d (f_i - f_c)$

$v_o(t) = 1\text{V/MHz} \times (2 - 3)\text{ MHz} = -1\text{V}$




v_{FM}
Frequency Demodulator
$v_o(t)$
When f_i = 1 MHz
k_d = 1 V/MHz
f_c = 3MHz
$v_o(t) = k_d (f_i - f_c)$
$v_o(t)$ = 1V/MHz x (1 - 3) MHz = -2V
$f_i(t)$ (MHz)
5
4
3
2
1
1
2
3
4
5
6
7
8
Time (μs)
$v_o(t)$ (volt)
2
1
0
-1
-2
1
2
3
4
5
6
7
8
Time (μs)



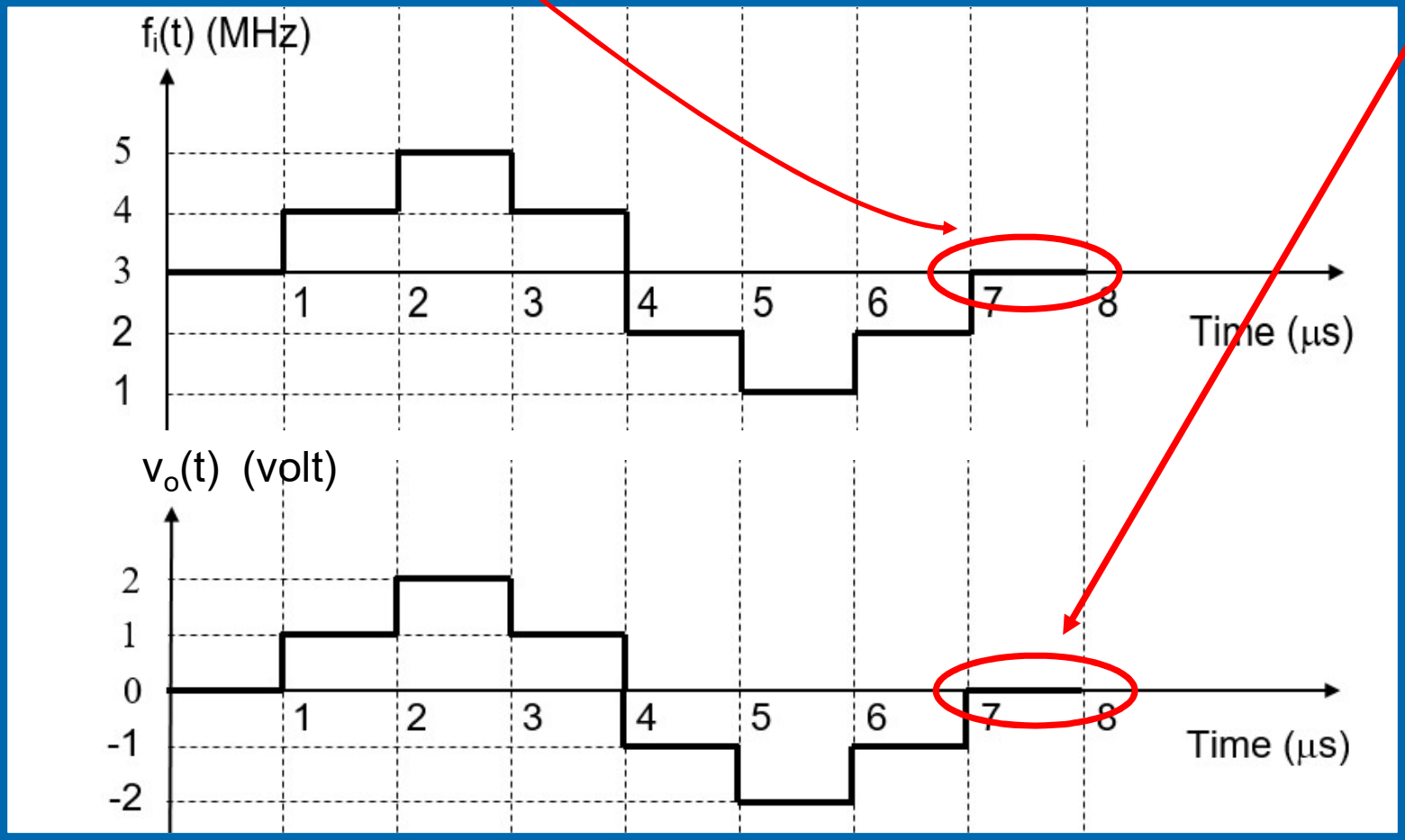
When $f_i = f_c = 3MHz$

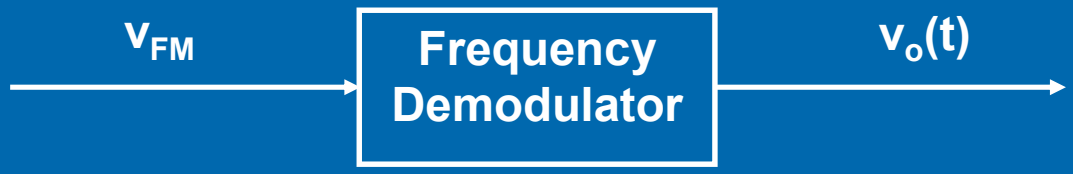
$k_d = 1$ V/MHz

$f_c = 3MHz$

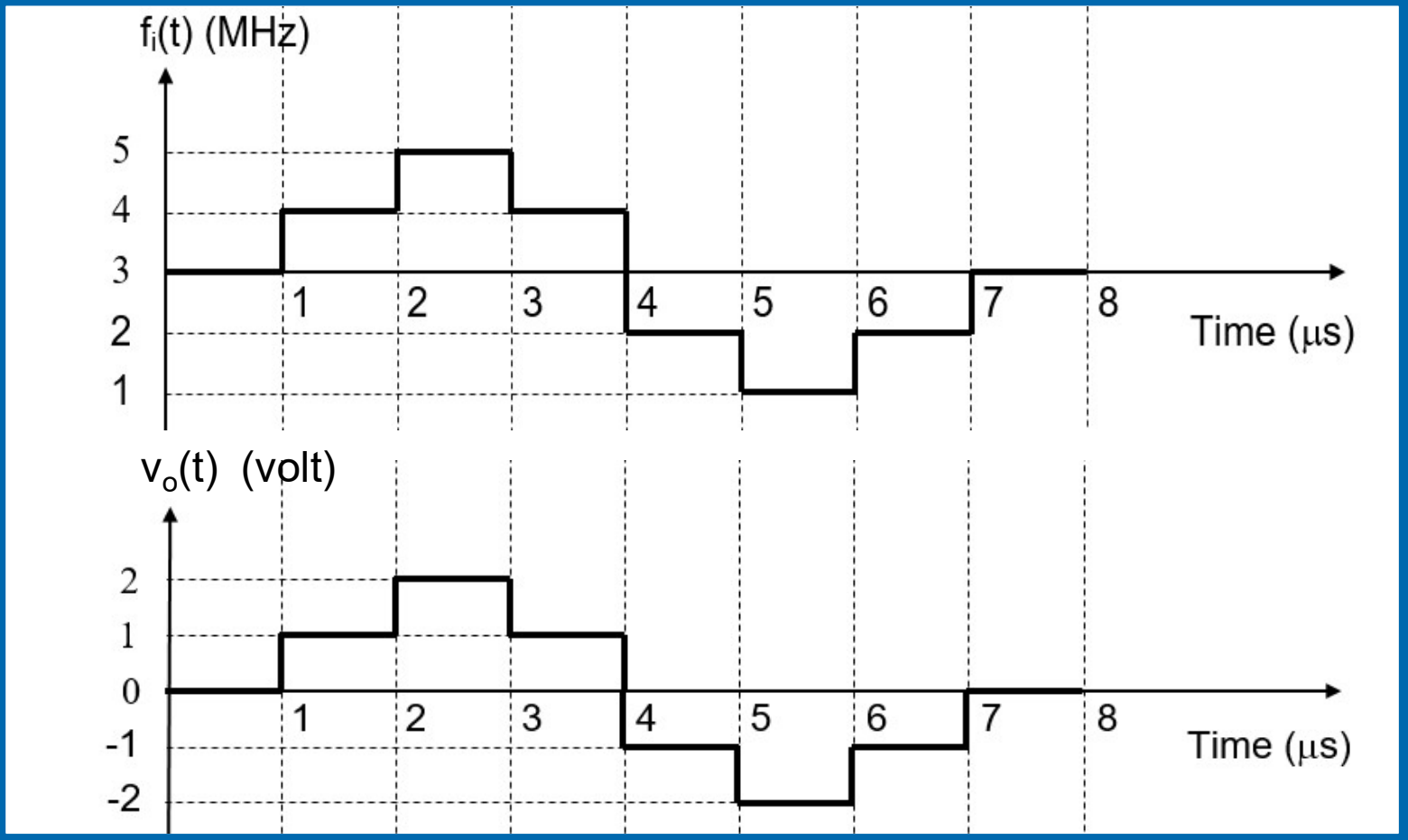
$v_o(t) = k_d (f_i - f_c)$

$v_o(t) = 1V/MHz \times (3 - 3)\ MHz = 0V$





Convert frequency variation to voltage variation



End

CHAPTER 6

(Part 3 of 4)