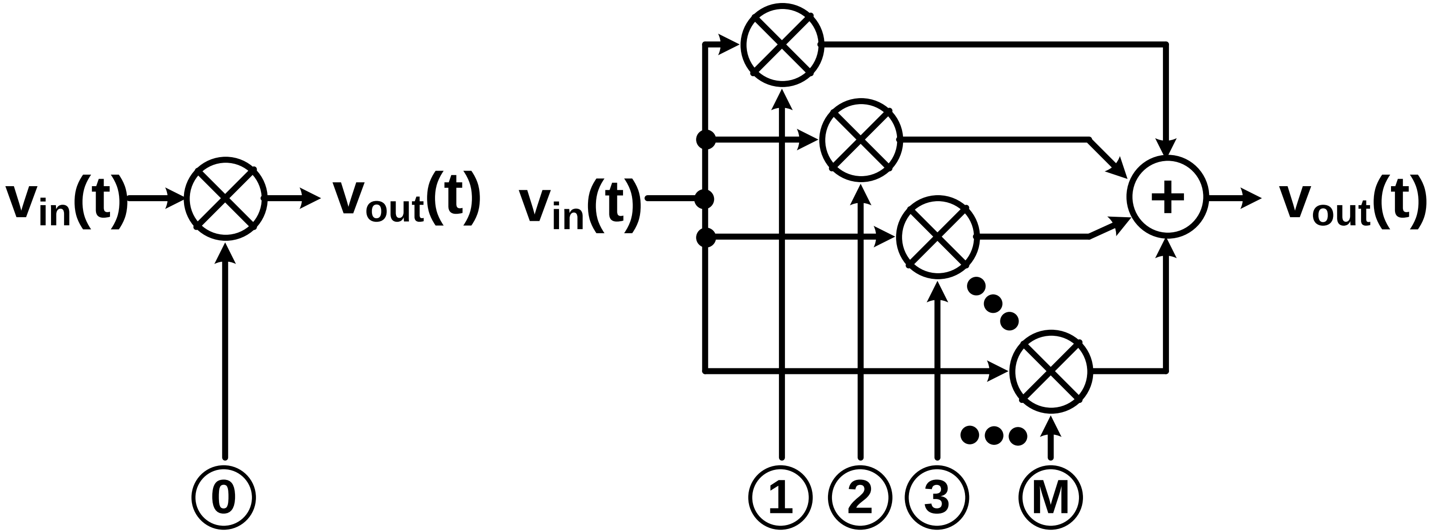
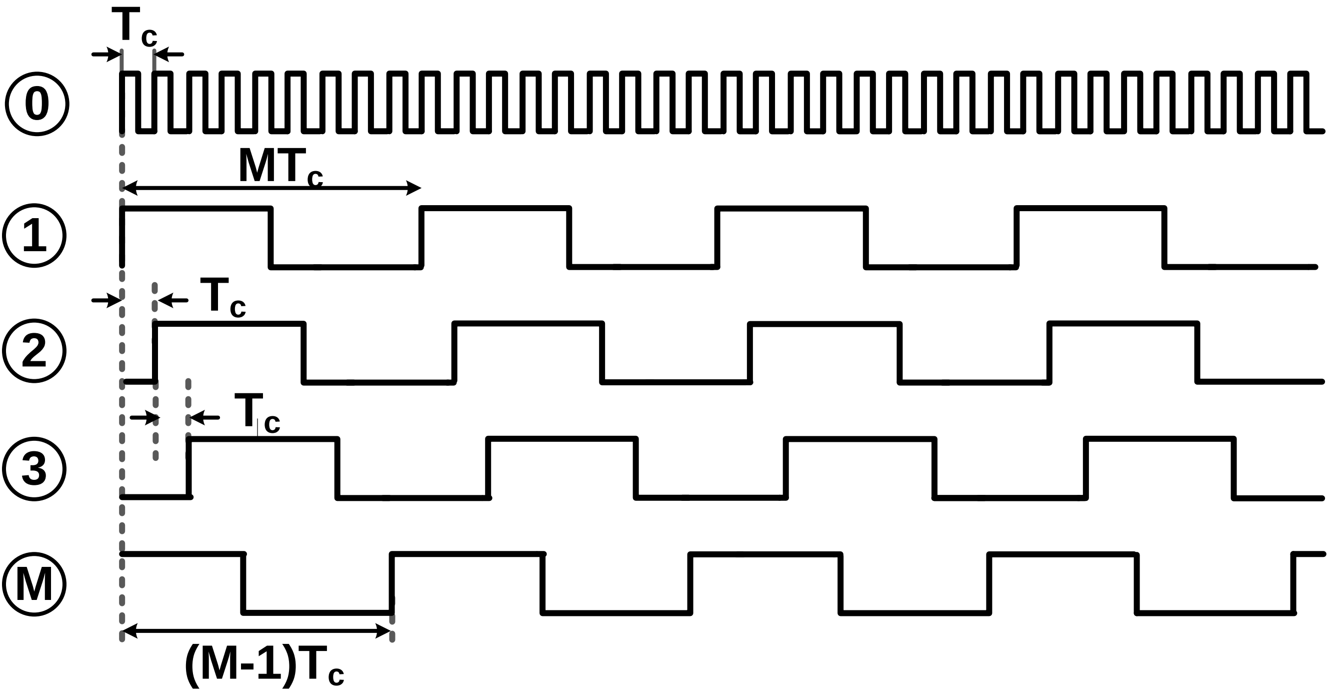
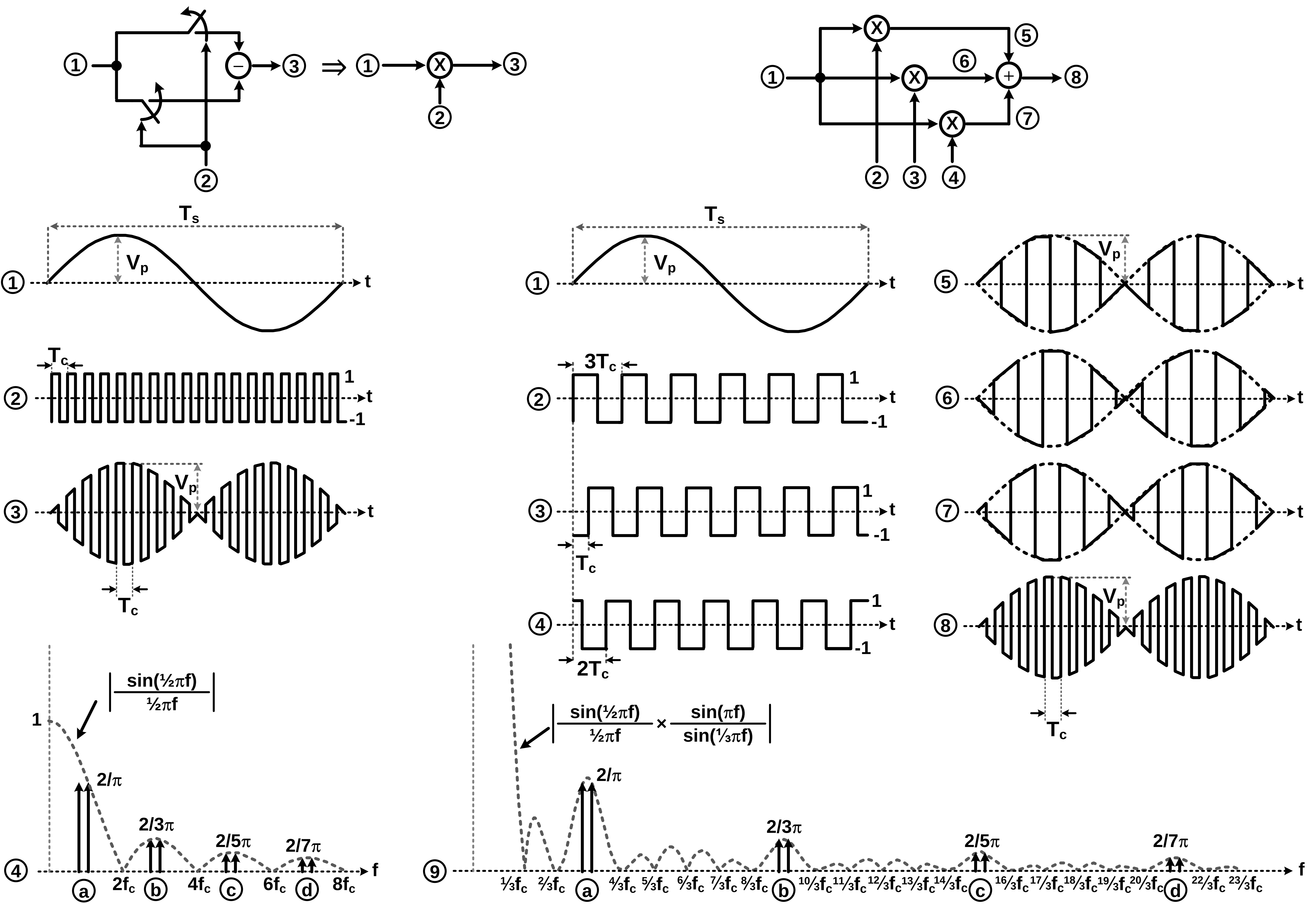


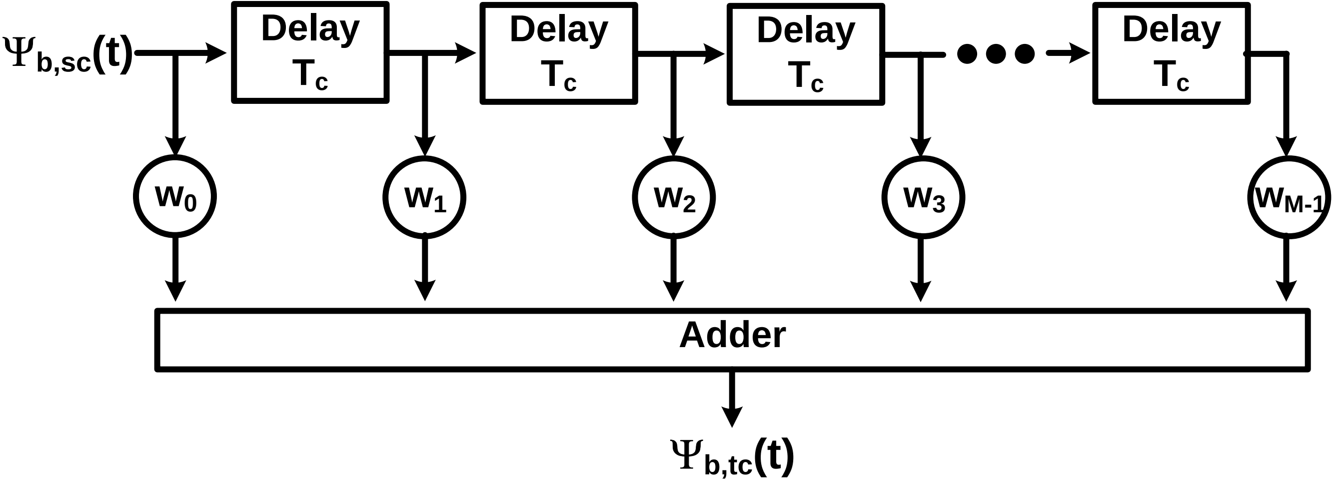
$v_{in}(t)$
$v_{out}(t)$
0
$v_{in}(t)$
+
$v_{out}(t)$
1
2
3
M



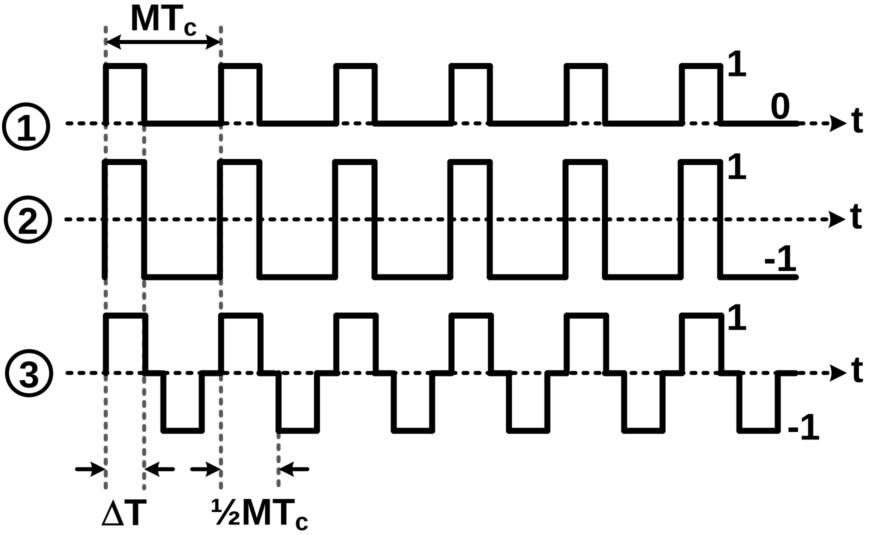
T_c
0
MT_c
1
T_c
2
T_c
3
M
$(M-1)T_c$



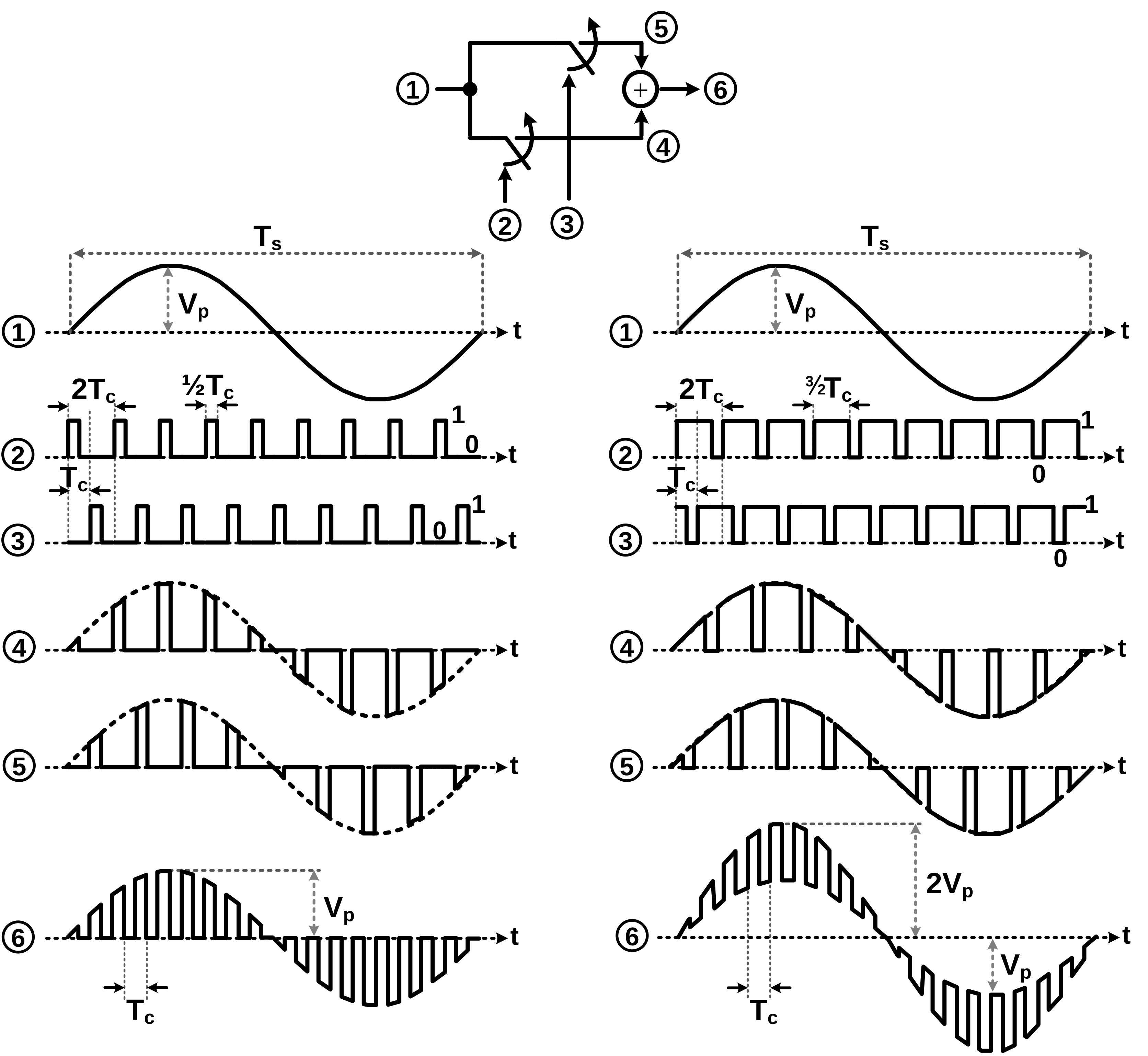
① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨
X
+
Ts
Vp
t
Tc
3Tc
2Tc
1
-1
|sin(½πf) / ½πf|
|sin(½πf) / ½πf × sin(πf) / sin(⅓πf)|
2/π
2/3π
2/5π
2/7π
f
2fc
4fc
6fc
8fc
ⓐ ⓑ ⓒ ⓓ
⅓fc ⅔fc 4⁄3fc 5⁄3fc 6⁄3fc 7⁄3fc 8⁄3fc 10⁄3fc 11⁄3fc 12⁄3fc 13⁄3fc 14⁄3fc 16⁄3fc 17⁄3fc 18⁄3fc 19⁄3fc 20⁄3fc 22⁄3fc 23⁄3fc



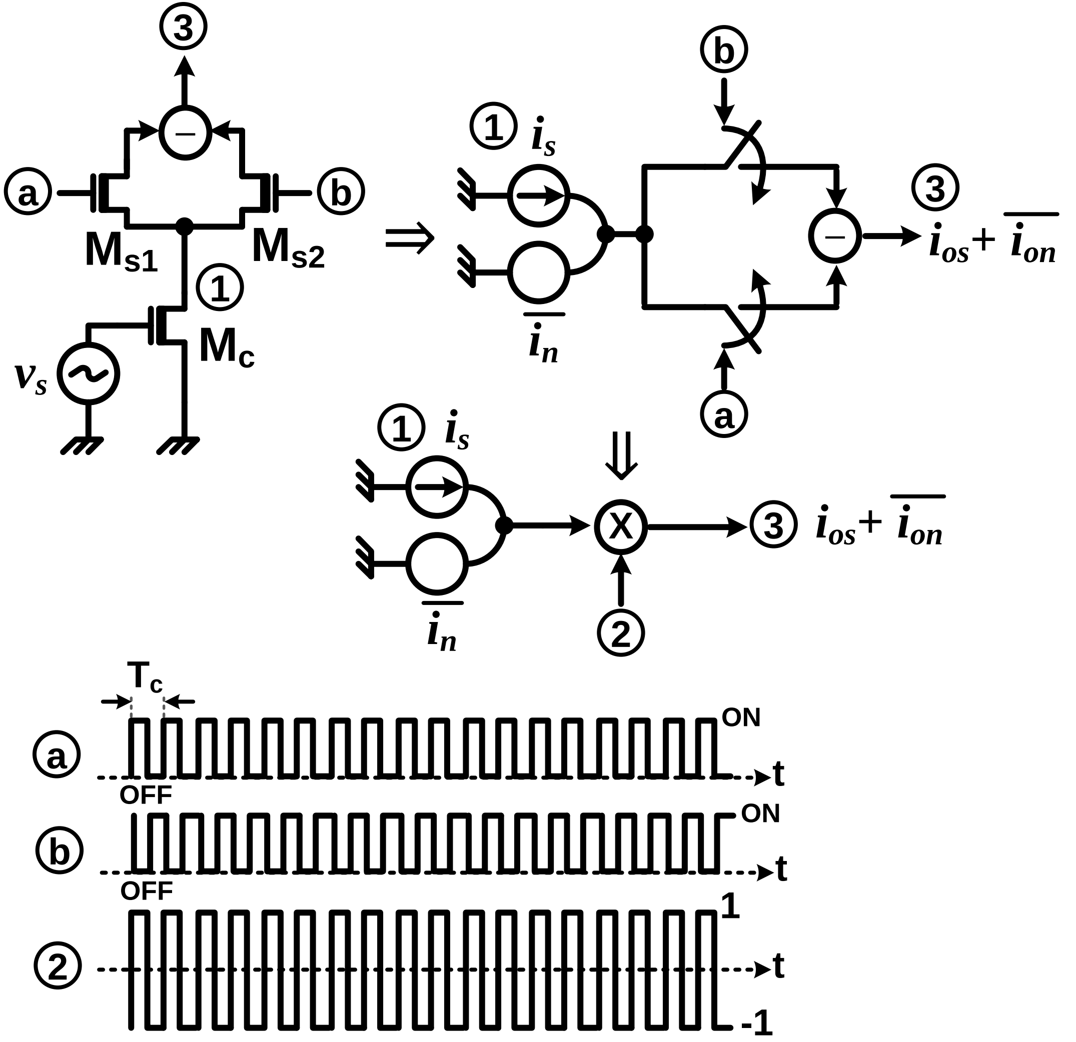
$\Psi_{b,sc}(t)$
Delay
T_c
Delay
T_c
Delay
T_c
Delay
T_c
w_0
w_1
w_2
w_3
w_{M-1}
Adder
$\Psi_{b,tc}(t)$



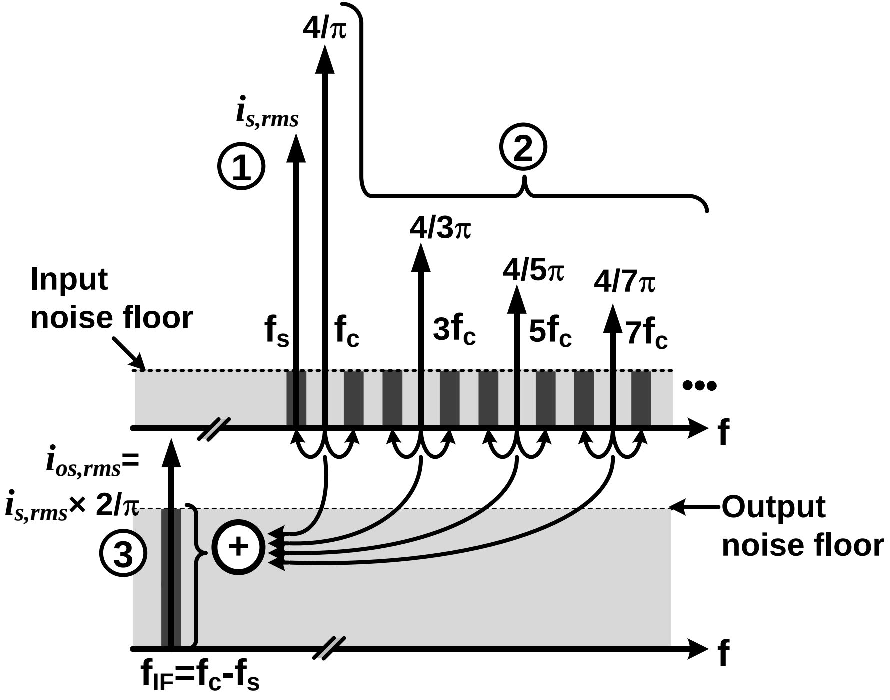
MTc
1
0
t
①
1
t
②
-1
1
③
t
-1
ΔT
½MTc



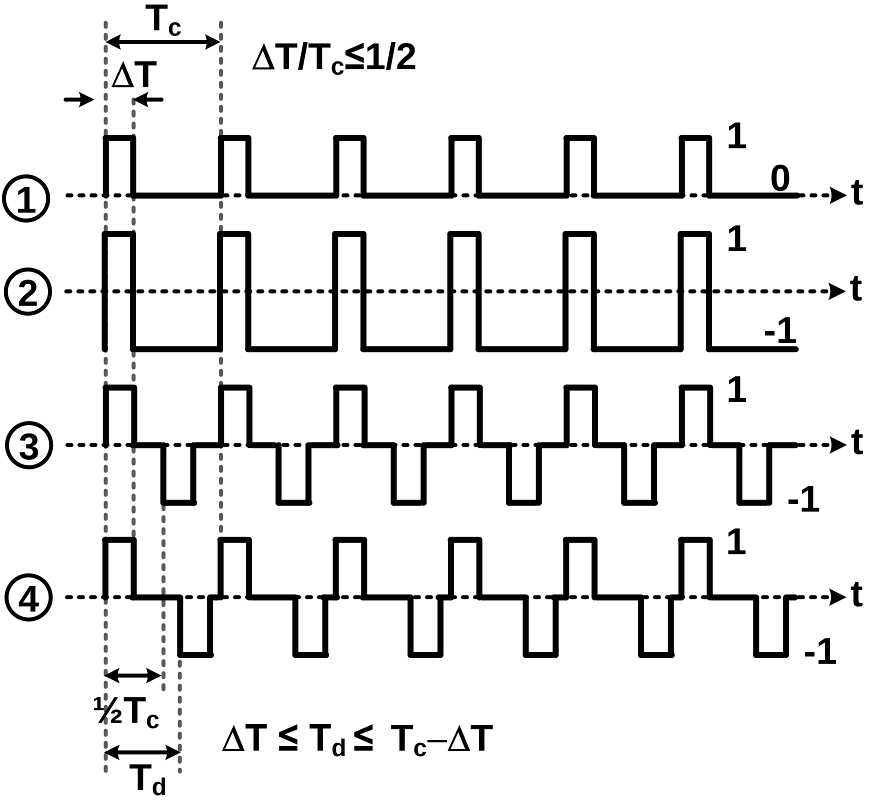
1
2
3
4
5
6
+
Ts
Vp
t
2Tc
½Tc
3/2Tc
Tc
1
0
2Vp



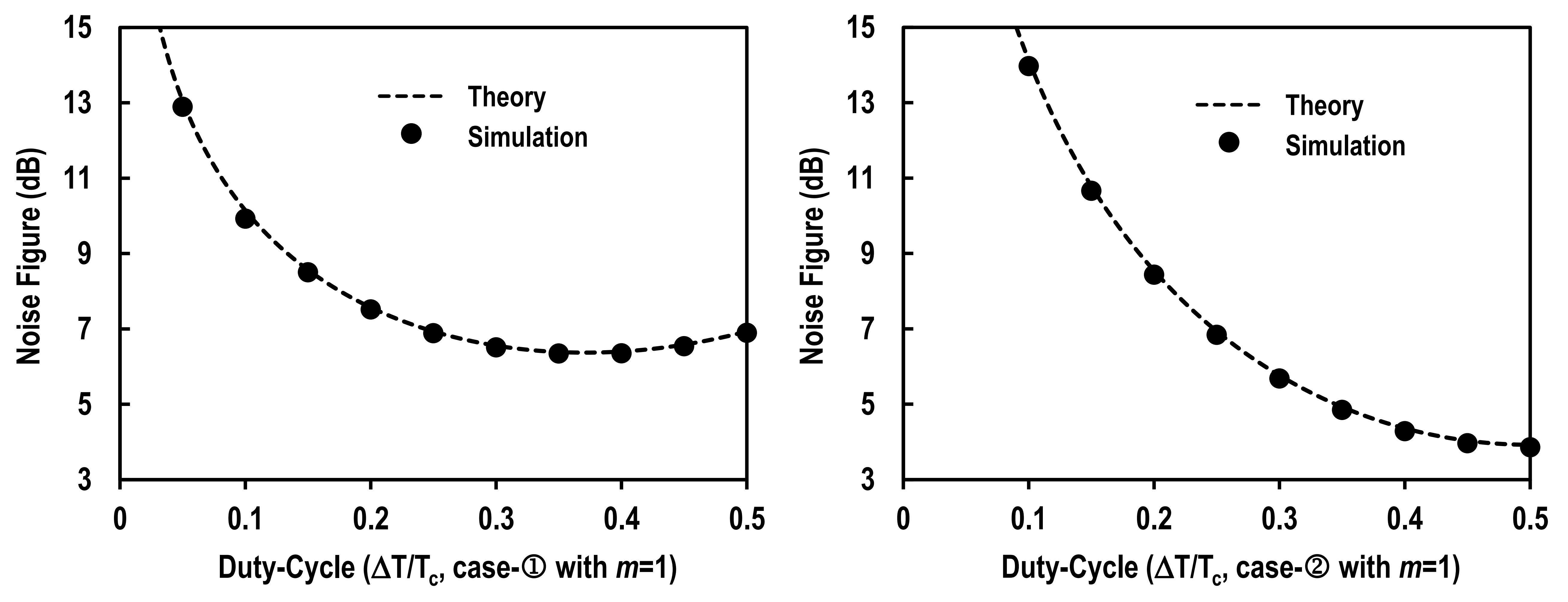
3
a
b
Ms1
Ms2
1
Mc
vs
⇒
1
is
b
3
ios+ ion
in
a
1
is
⇓
X
3
ios+ ion
in
2
Tc
ON
a
t
OFF
ON
b
t
OFF
1
2
t
-1



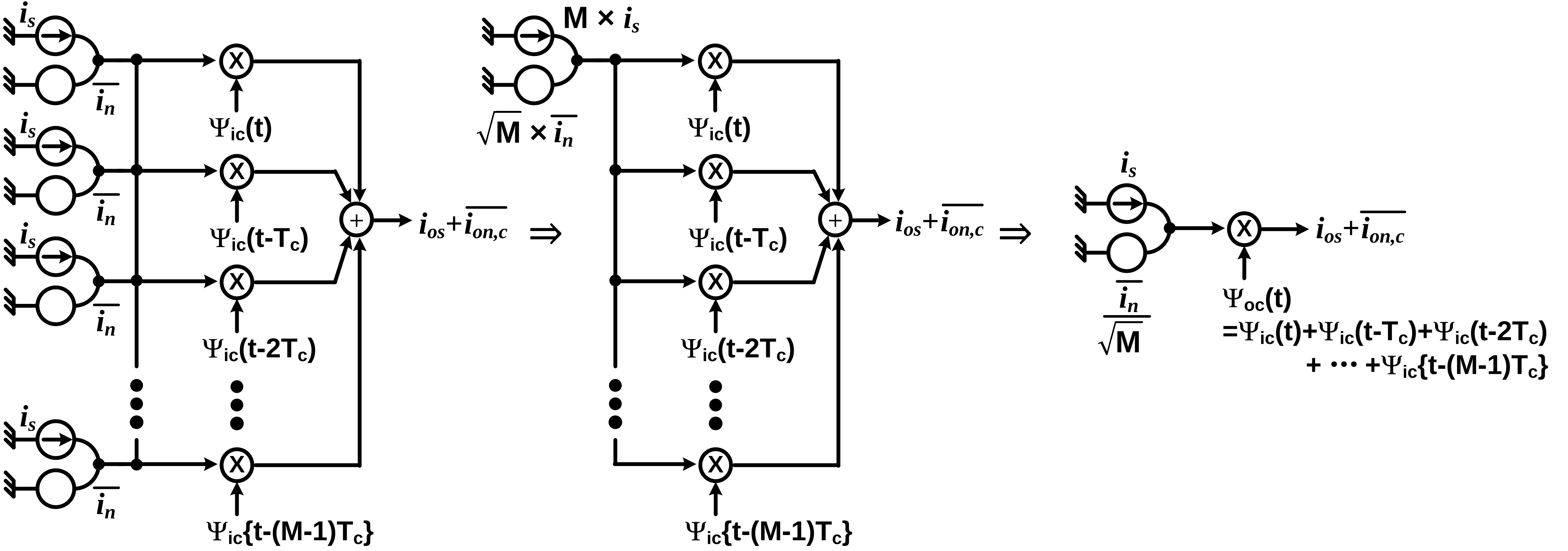
4/π
$i_{s,rms}$
1
2
4/3π
4/5π
4/7π
Input
noise floor
f_s
f_c
$3f_c$
$5f_c$
$7f_c$
f
$i_{os,rms}$=
$i_{s,rms}$× 2/π
3
+
Output
noise floor
f
$f_{IF}=f_c-f_s$



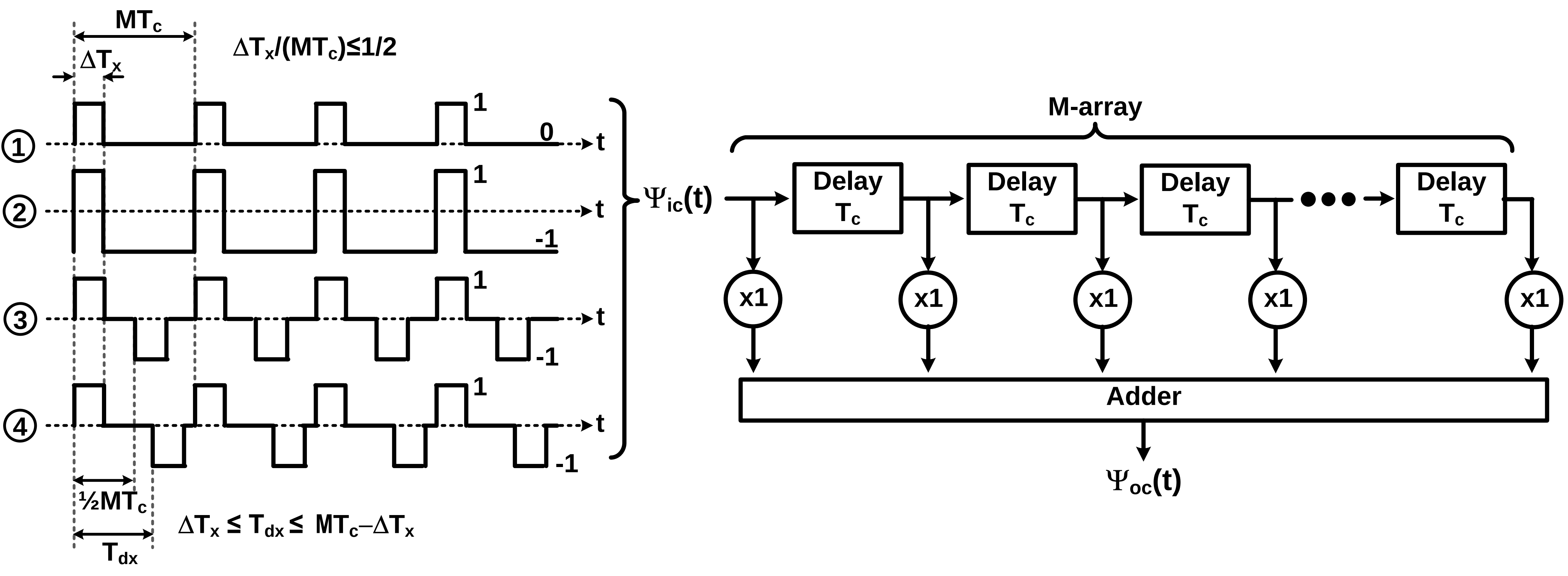
T_c
ΔT/T_c≤1/2
ΔT
1
0
t
①
1
②
t
-1
1
③
t
-1
1
④
t
-1
½T_c
ΔT ≤ T_d ≤ T_c–ΔT
T_d



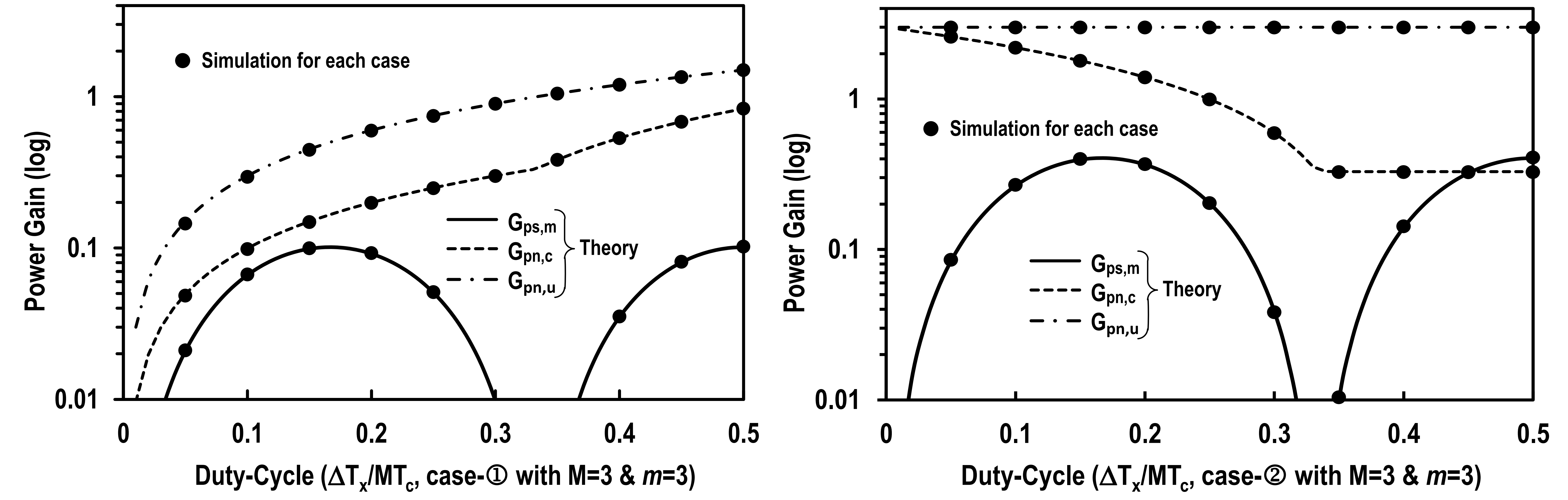
Theory
Simulation
Noise Figure (dB)
Duty-Cycle (ΔT/T_c, case-① with m=1)
Theory
Simulation
Noise Figure (dB)
Duty-Cycle (ΔT/T_c, case-② with m=1)



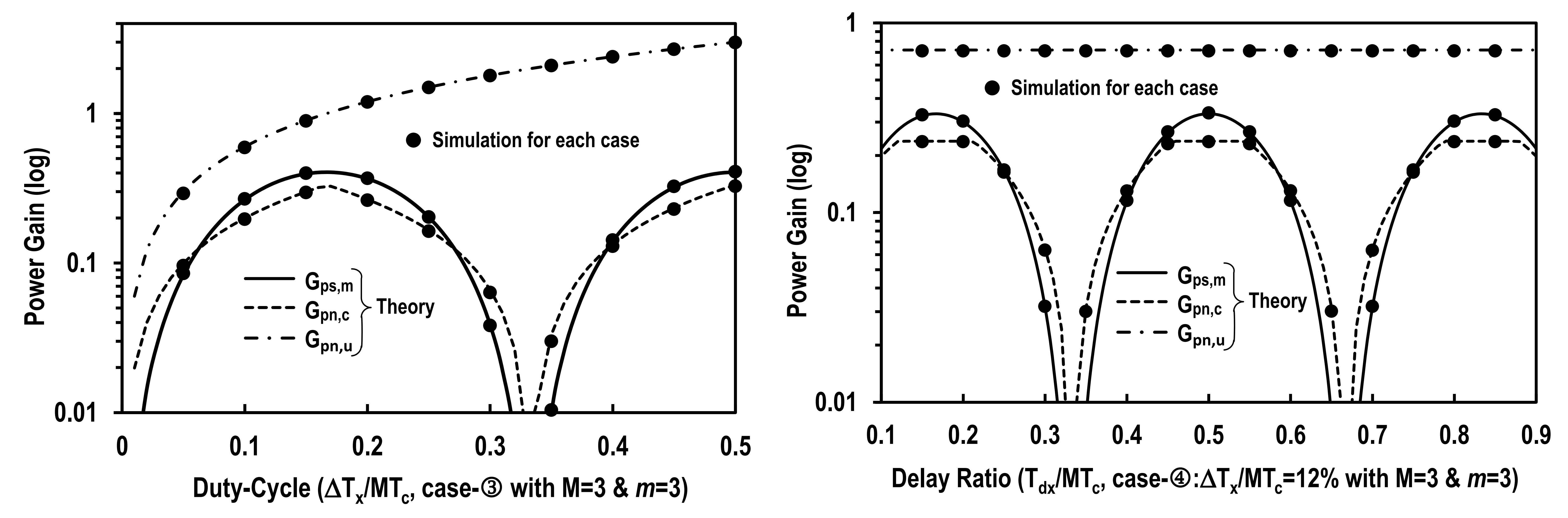
i_s
$\overline{i_n}$
X
$\Psi_{ic}(t)$
$\Psi_{ic}(t-T_c)$
$\Psi_{ic}(t-2T_c)$
$\Psi_{ic}\{t-(M-1)T_c\}$
+
$i_{os}+\overline{i_{on,c}}$
⇒
$M \times i_s$
$\sqrt{M} \times \overline{i_n}$
$\frac{\overline{i_n}}{\sqrt{M}}$
$\Psi_{oc}(t)$
$=\Psi_{ic}(t)+\Psi_{ic}(t-T_c)+\Psi_{ic}(t-2T_c)$
$+\cdots+\Psi_{ic}\{t-(M-1)T_c\}$



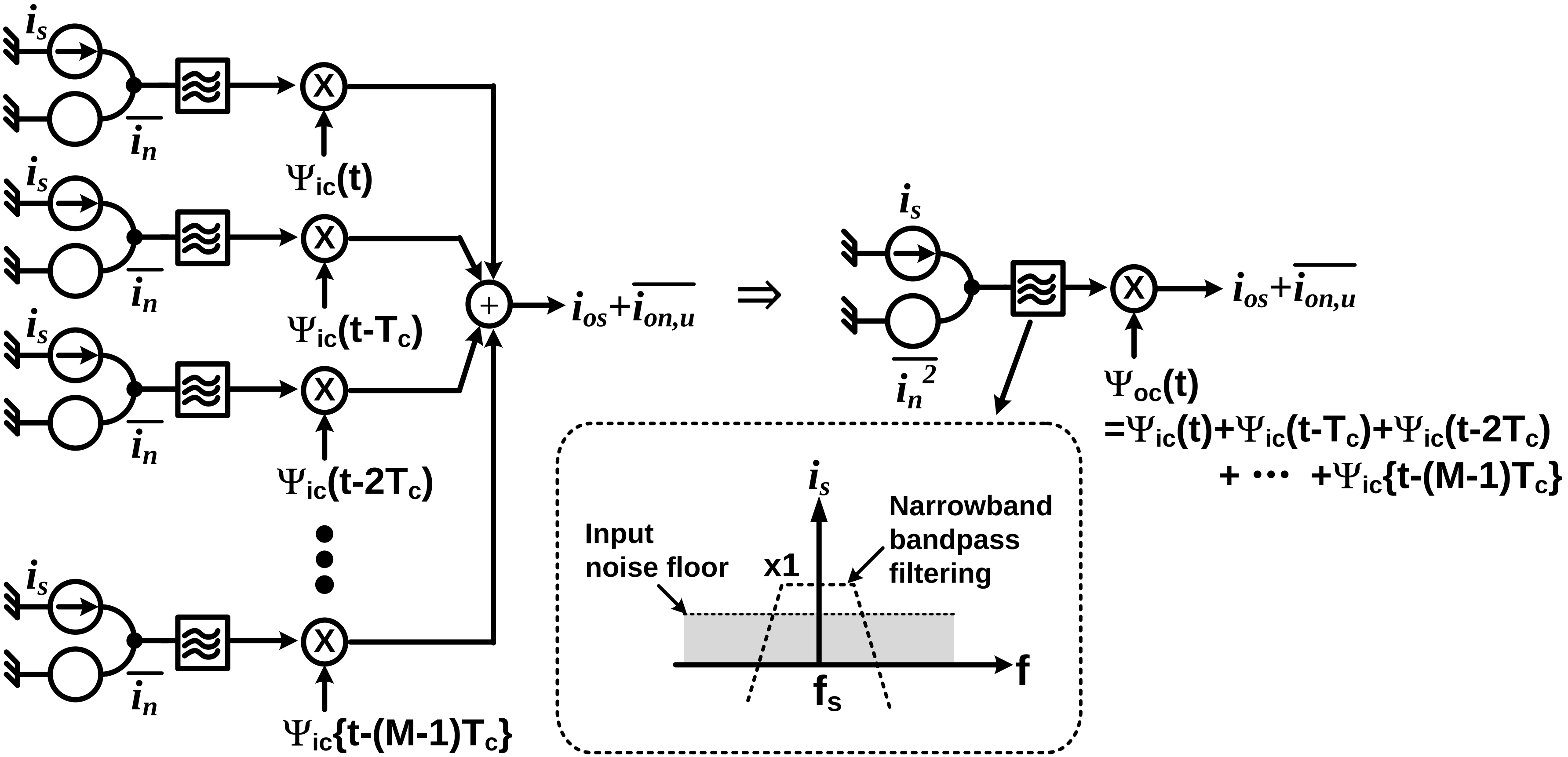
MT_c
$\Delta T_x/(MT_c) \leq 1/2$
ΔT_X
1
0
t
①
②
③
④
-1
$\Psi_{ic}(t)$
$\frac{1}{2}MT_c$
$\Delta T_x \leq T_{dx} \leq MT_c - \Delta T_x$
T_{dx}
M-array
Delay T_c
x1
Adder
$\Psi_{oc}(t)$



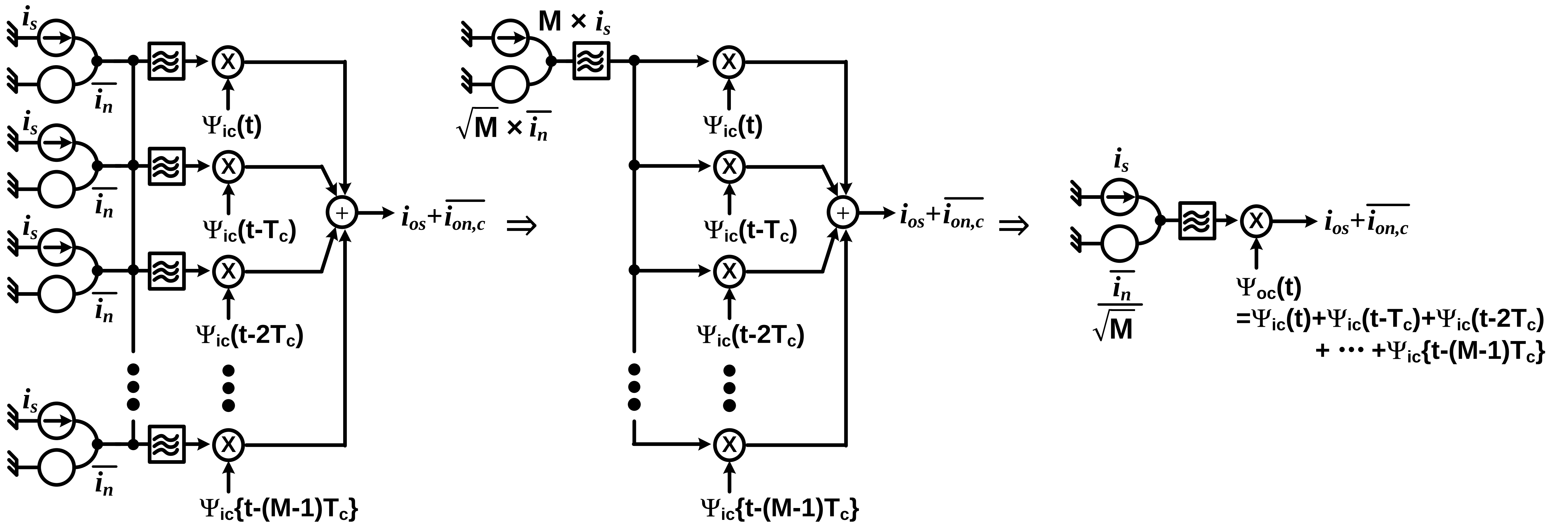
Power Gain (log)
Simulation for each case
$G_{ps,m}$
$G_{pn,c}$
$G_{pn,u}$
Theory
0.01
0.1
1
0
0.1
0.2
0.3
0.4
0.5
Duty-Cycle ($\Delta T_x/MT_c$, case-① with M=3 & m=3)
Duty-Cycle ($\Delta T_x/MT_c$, case-② with M=3 & m=3)



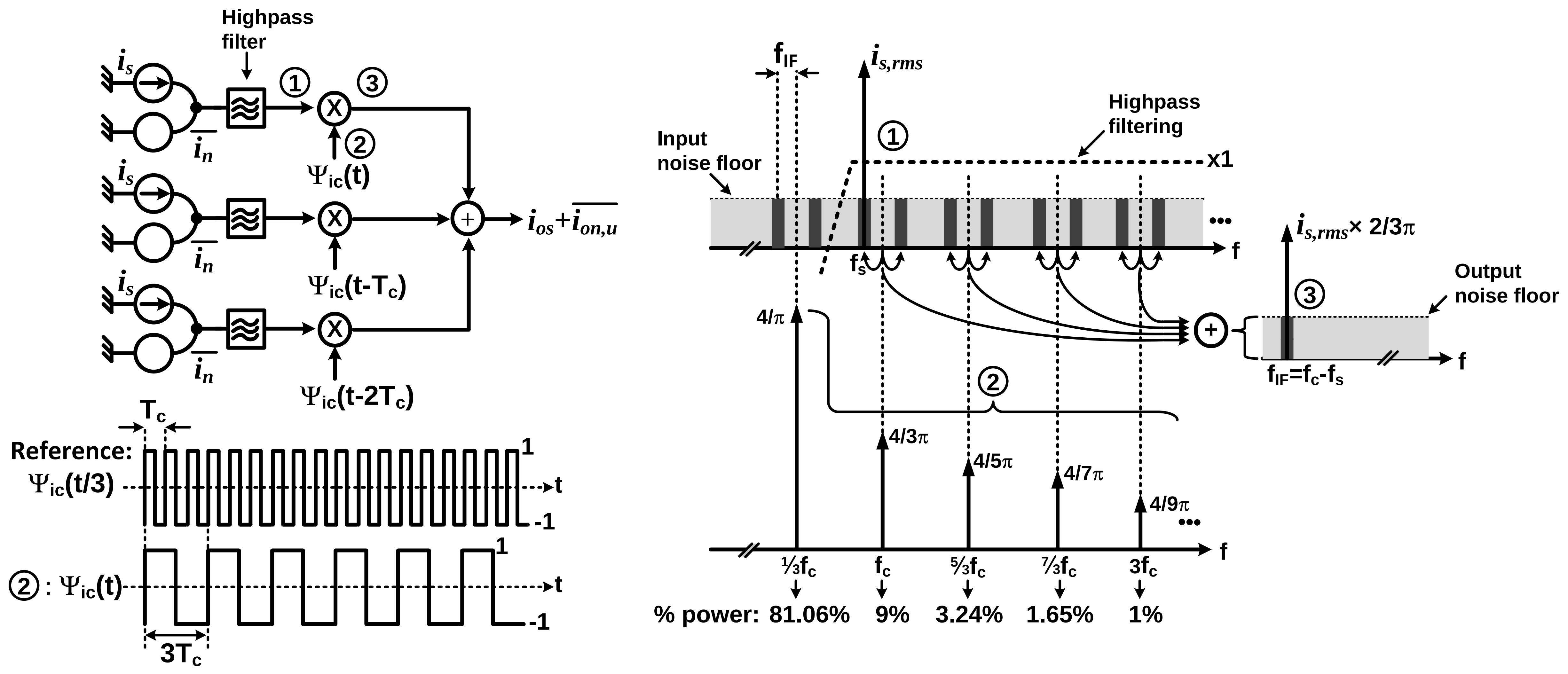
Power Gain (log)
Duty-Cycle (ΔTx/MTc, case-③ with M=3 & m=3)
Simulation for each case
Gps,m
Gpn,c
Gpn,u
Theory
0.01
0.1
1
0
0.1
0.2
0.3
0.4
0.5
Delay Ratio (Tdx/MTc, case-④:ΔTx/MTc=12% with M=3 & m=3)
0.6
0.7
0.8
0.9



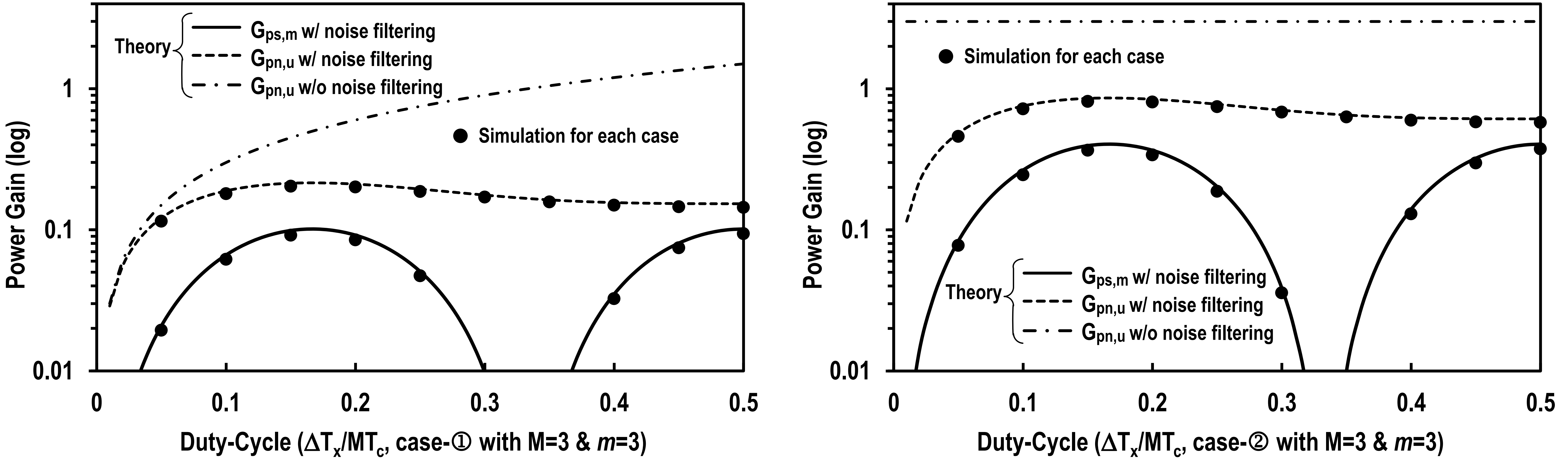
i_s
$\overline{i_n}$
$\Psi_{ic}(t)$
$\Psi_{ic}(t-T_c)$
$\Psi_{ic}(t-2T_c)$
$\Psi_{ic}\{t-(M-1)T_c\}$
$i_{os}+\overline{i_{on,u}}$
$\Rightarrow$
$\overline{i_n^{\,2}}$
$\Psi_{oc}(t)$
$=\Psi_{ic}(t)+\Psi_{ic}(t-T_c)+\Psi_{ic}(t-2T_c)$
$+\cdots+\Psi_{ic}\{t-(M-1)T_c\}$
Input
noise floor
x1
Narrowband
bandpass
filtering
f_s
f



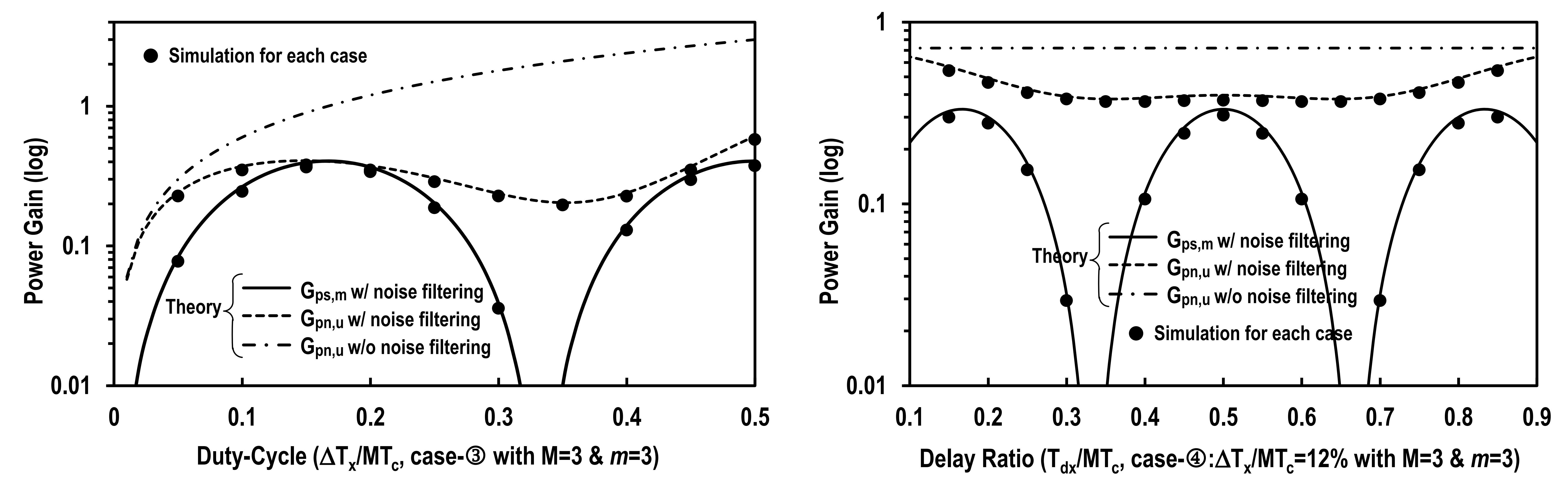
i_s
$\overline{i_n}$
$\Psi_{ic}(t)$
$\Psi_{ic}(t\text{-}T_c)$
$\Psi_{ic}(t\text{-}2T_c)$
$\Psi_{ic}\{t\text{-}(M\text{-}1)T_c\}$
$i_{os}+\overline{i_{on,c}}$
$\Rightarrow$
$M \times i_s$
$\sqrt{M} \times \overline{i_n}$
$\frac{\overline{i_n}}{\sqrt{M}}$
$\Psi_{oc}(t)$
$=\Psi_{ic}(t)+\Psi_{ic}(t\text{-}T_c)+\Psi_{ic}(t\text{-}2T_c)$
$+ \cdots +\Psi_{ic}\{t\text{-}(M\text{-}1)T_c\}$



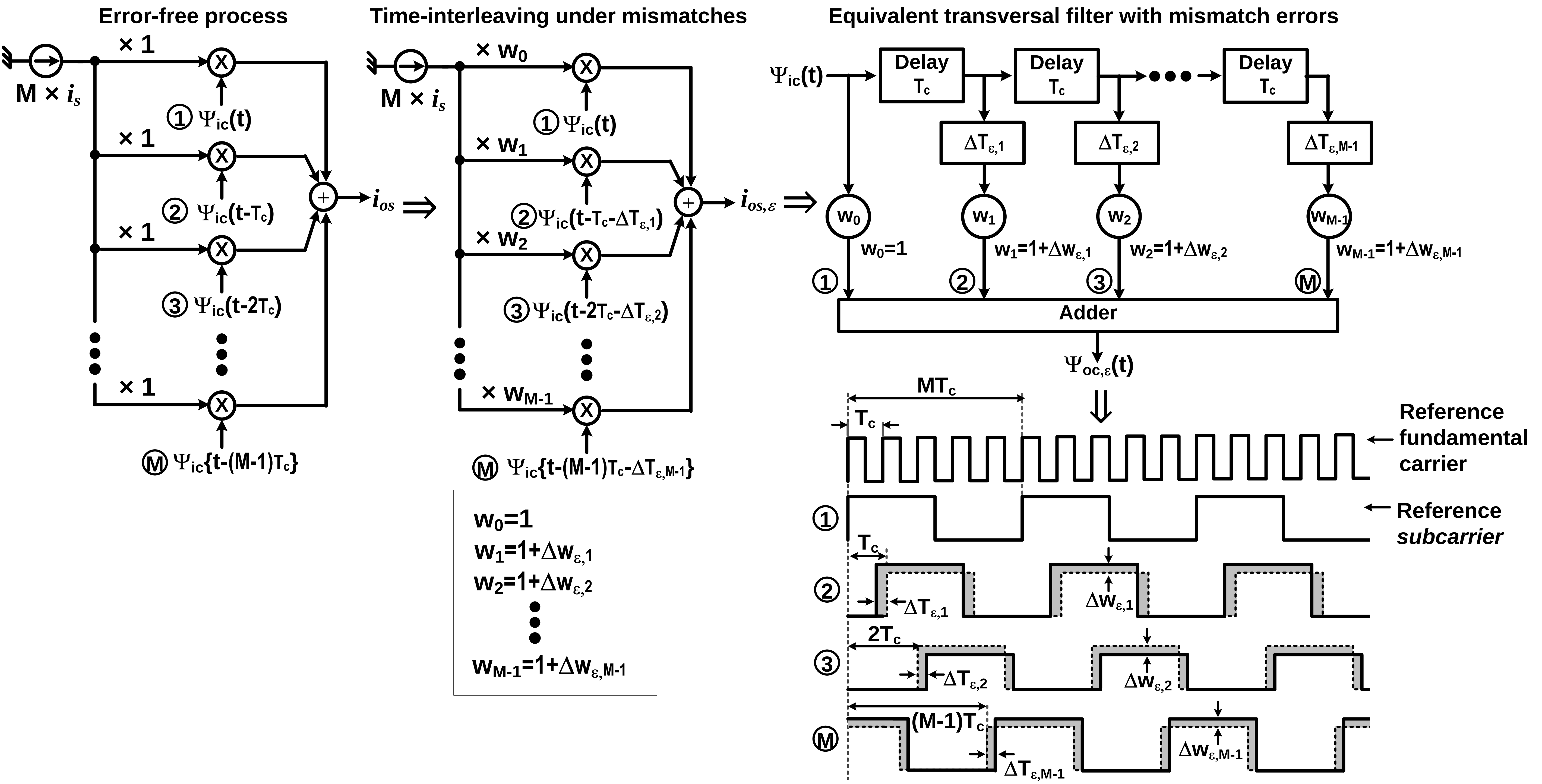
Highpass filter
i_s
$\overline{i_n}$
1
2
3
$\Psi_{ic}(t)$
$\Psi_{ic}(t-T_c)$
$\Psi_{ic}(t-2T_c)$
$i_{os}+\overline{i_{on,u}}$
T_c
Reference:
$\Psi_{ic}(t/3)$
1
-1
t
2 : $\Psi_{ic}(t)$
$3T_c$
f_{IF}
$i_{s,rms}$
Highpass filtering
Input noise floor
x1
f_s
f
$4/\pi$
$4/3\pi$
$4/5\pi$
$4/7\pi$
$4/9\pi$
$i_{s,rms}\times 2/3\pi$
Output noise floor
$f_{IF}=f_c-f_s$
⅓f_c
f_c
⅗f_c
⅞f_c
$3f_c$
% power: 81.06% 9% 3.24% 1.65% 1%

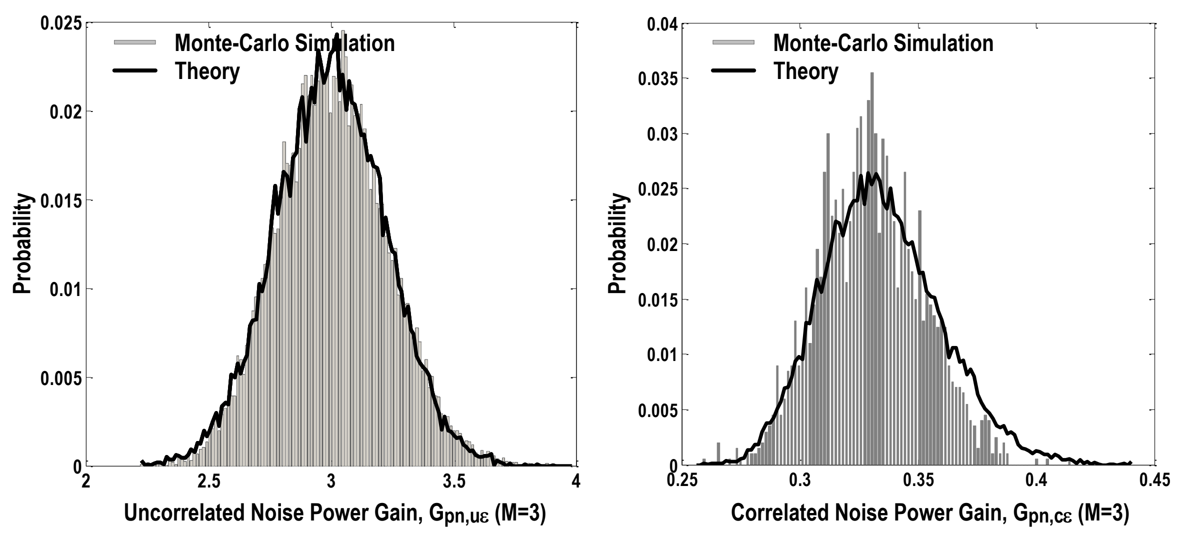


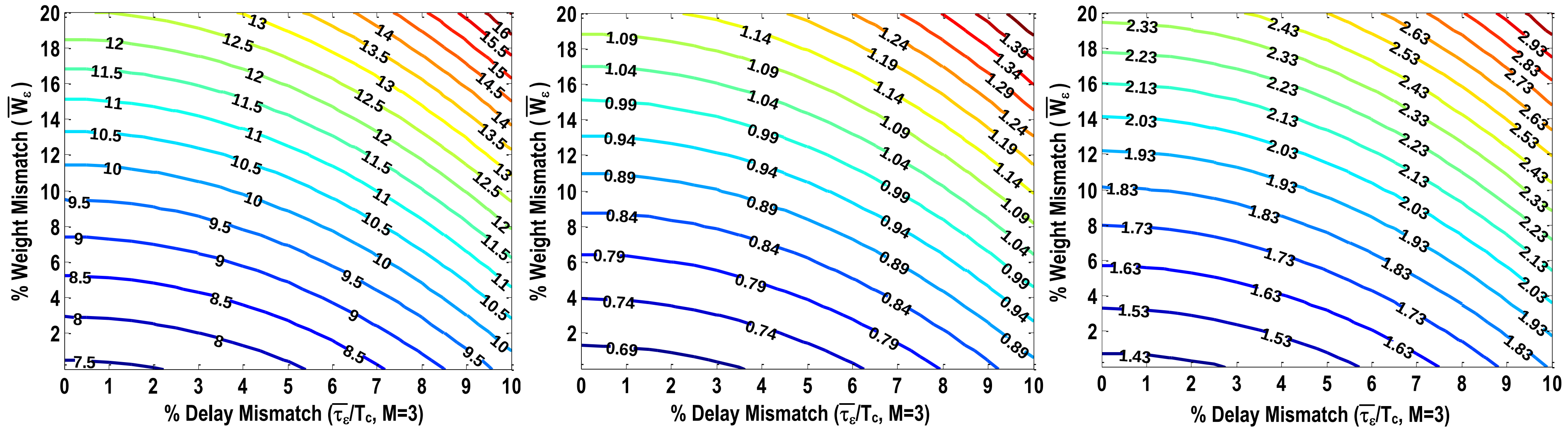
Theory
Gps,m w/ noise filtering
Gpn,u w/ noise filtering
Gpn,u w/o noise filtering
Simulation for each case
Power Gain (log)
1
0.1
0.01
0
0.1
0.2
0.3
0.4
0.5
Duty-Cycle (ΔTx/MTc, case-① with M=3 & m=3)
Simulation for each case
Theory
Gps,m w/ noise filtering
Gpn,u w/ noise filtering
Gpn,u w/o noise filtering
Power Gain (log)
Duty-Cycle (ΔTx/MTc, case-② with M=3 & m=3)



Simulation for each case
Theory
Gps,m w/ noise filtering
Gpn,u w/ noise filtering
Gpn,u w/o noise filtering
Power Gain (log)
0.01
0.1
1
0
0.1
0.2
0.3
0.4
0.5
Duty-Cycle (ΔTx/MTc, case-③ with M=3 & m=3)
Theory
Gps,m w/ noise filtering
Gpn,u w/ noise filtering
Gpn,u w/o noise filtering
Simulation for each case
Power Gain (log)
0.01
0.1
1
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Delay Ratio (Tdx/MTc, case-④:ΔTx/MTc=12% with M=3 & m=3)


Error-free process
Time-interleaving under mismatches
Equivalent transversal filter with mismatch errors
M × i_s
× 1
① Ψic(t)
② Ψic(t-Tc)
③ Ψic(t-2Tc)
Ⓜ Ψic{t-(M-1)Tc}
i_os
× w0
× w1
× w2
× wM-1
① Ψic(t)
② Ψic(t-Tc-ΔTε,1)
③ Ψic(t-2Tc-ΔTε,2)
Ⓜ Ψic{t-(M-1)Tc-ΔTε,M-1}
i_os,ε
w0=1
w1=1+Δwε,1
w2=1+Δwε,2
wM-1=1+Δwε,M-1
Ψic(t)
Delay Tc
ΔTε,1
ΔTε,2
ΔTε,M-1
Adder
Ψoc,ε(t)
MTc
Tc
Reference fundamental carrier
Reference subcarrier
2Tc
(M-1)Tc
Δwε,1
Δwε,2
Δwε,M-1


Monte-Carlo Simulation
Theory
Probability
Uncorrelated Noise Power Gain, $G_{pn,u\varepsilon}$ (M=3)
0.025
0.02
0.015
0.01
0.005
0
2
2.5
3
3.5
4
Monte-Carlo Simulation
Theory
Probability
Correlated Noise Power Gain, $G_{pn,c\varepsilon}$ (M=3)
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0.25
0.3
0.35
0.4
0.45



% Weight Mismatch ($\overline{W_\varepsilon}$)
% Delay Mismatch ($\overline{\tau_\varepsilon}/T_c$, M=3)
% Weight Mismatch ($\overline{W_\varepsilon}$)
% Delay Mismatch ($\overline{\tau_\varepsilon}/T_c$, M=3)
% Weight Mismatch ($\overline{W_\varepsilon}$)
% Delay Mismatch ($\overline{\tau_\varepsilon}/T_c$, M=3)

	$G_{ps,m}$	G_{pn}
①	$\left\{\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T}{T_c}\right)\right\}^2$	$\frac{\Delta T}{T_c}$
②	$\left\{\frac{2}{m\pi}\sin\left(m\pi\frac{\Delta T}{T_c}\right)\right\}^2$	1
③	$\left\{\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T}{T_c}\right) \times (1-\cos m\pi)\right\}^2$	$2\frac{\Delta T}{T_c}$
④	$\left\{\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T}{T_c}\right) \times \sqrt{2-2\cos\left(2m\pi\frac{T_d}{T_c}\right)}\right\}^2$	$2\frac{\Delta T}{T_c}$

Note: ①, ②, ③, and ④ represent each subcarrier type depicted in Fig. 7, respectively.

	$G_{ps,m}$	$G_{pn,u}$	$G_{pn,c}$
①	$\left\{\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$	$\frac{\Delta T_x}{MT_c}\times M=\frac{\Delta T_x}{T_c}$	$\frac{1}{M}\sum_{m=-\infty}^{\infty}\left\{\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$
②	$\left\{\frac{2}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$	M	$M\left(2\frac{\Delta T_x}{MT_c}-1\right)^2+\frac{2}{M}\sum_{m=1}^{\infty}\left\{\frac{2}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$
③	$\left\{\begin{matrix}\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\\ \times(1-\cos m\pi)\end{matrix}\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$	$2\frac{\Delta T_x}{MT_c}\times M=2\frac{\Delta T_x}{T_c}$	$\frac{1}{M}\sum_{m=-\infty}^{\infty}\left\{\begin{matrix}\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\\ \times(1-\cos m\pi)\end{matrix}\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$
④	$\left\{\begin{matrix}\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\\ \times\sqrt{2-2\cos\left(2m\pi\frac{T_{dx}}{MT_c}\right)}\end{matrix}\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$	$2\frac{\Delta T_x}{MT_c}\times M=2\frac{\Delta T_x}{T_c}$	$\frac{1}{M}\sum_{m=-\infty}^{\infty}\left\{\begin{matrix}\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\\ \times\sqrt{2-2\cos\left(2m\pi\frac{T_{dx}}{MT_c}\right)}\end{matrix}\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$

***Note: ①, ②, ③, and ④ represent each subcarrier type depicted in Fig. 10, respectively.**

	$\mathbf{G_{pn,u}}$	$\mathbf{G_{pn,c}}$
①	$\left(\frac{\Delta T_x}{MT_c} - \left(\frac{\Delta T_x}{MT_c}\right)^2 - 2\sum_{k=1}^{M-1}\left\{(1-\delta_k{}^2)\left(\frac{1}{k\pi}\sin\left(k\pi\frac{\Delta T_x}{MT_c}\right)\right)^2\right\}\right) \times M$	$\frac{2}{M}\sum_{m=1}^{\infty}\left\{\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$
②	$\left(1 - \left(1 - \frac{2\Delta T_x}{MT_c}\right)^2 - 2\sum_{k=1}^{M-1}\left\{(1-\delta_k{}^2)\left(\frac{2}{k\pi}\sin\left(k\pi\frac{\Delta T_x}{MT_c}\right)\right)^2\right\}\right) \times M$	$\frac{2}{M}\sum_{m=1}^{\infty}\left\{\frac{2}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$
③	$2\left(\frac{\Delta T_x}{MT_c} - \sum_{k=1}^{M-1}\left\{(1-\delta_k{}^2)\left(\begin{matrix}\frac{1}{k\pi}\sin\left(k\pi\frac{\Delta T_x}{MT_c}\right)\\ \times(1-\cos k\pi)\end{matrix}\right)^2\right\}\right) \times M$	$\frac{1}{M}\sum_{m=-\infty}^{\infty}\left\{\begin{matrix}\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\\ \times(1-\cos m\pi)\end{matrix}\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$
④	$2\left(\frac{\Delta T_x}{MT_c} - \sum_{k=1}^{M-1}\left\{(1-\delta_k{}^2)\left(\begin{matrix}\frac{1}{k\pi}\sin\left(k\pi\frac{\Delta T_x}{MT_c}\right)\\ \times\sqrt{2-2\cos\left(2k\pi\frac{T_{dx}}{MT_c}\right)}\end{matrix}\right)^2\right\}\right) \times M$	$\frac{1}{M}\sum_{m=-\infty}^{\infty}\left\{\begin{matrix}\frac{1}{m\pi}\sin\left(m\pi\frac{\Delta T_x}{MT_c}\right)\\ \times\sqrt{2-2\cos\left(2m\pi\frac{T_{dx}}{MT_c}\right)}\end{matrix}\right\}^2\left(\frac{\sin m\pi}{\sin\frac{m\pi}{M}}\right)^2$

***Note: ①, ②, ③, and ④ represent each subcarrier type depicted in Fig. 10, respectively.**