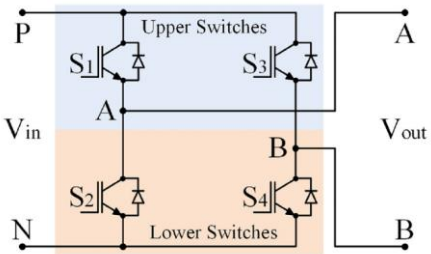
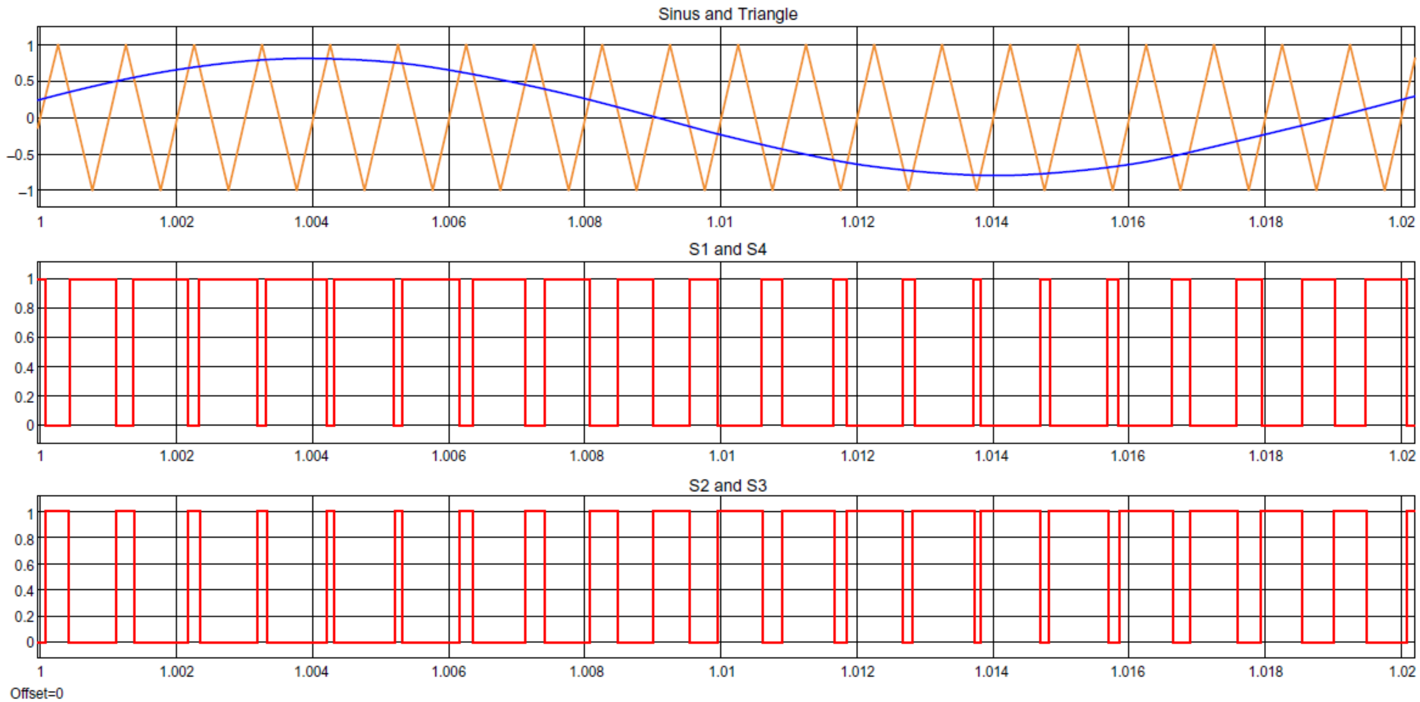
Voltage Control of Single-Phase Inverters

- Commonly-used Techniques
  - Bipolar Sinusoidal-Pulse-Width-Modulation
  - Unipolar Sinusoidal-Pulse-Width-Modulation
  - Single-Pulse-Width-Modulation
  - Multiple-Pulse-Width-Modulation
  - Sinusoidal-Pulse-Width-Modulation
  - Modified-Sinusoidal-Pulse-Width-Modulation
  - Phase-Displacement Control

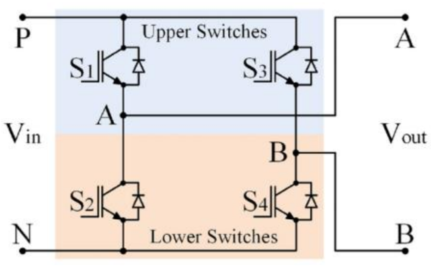
❑ Bipolar SPWM

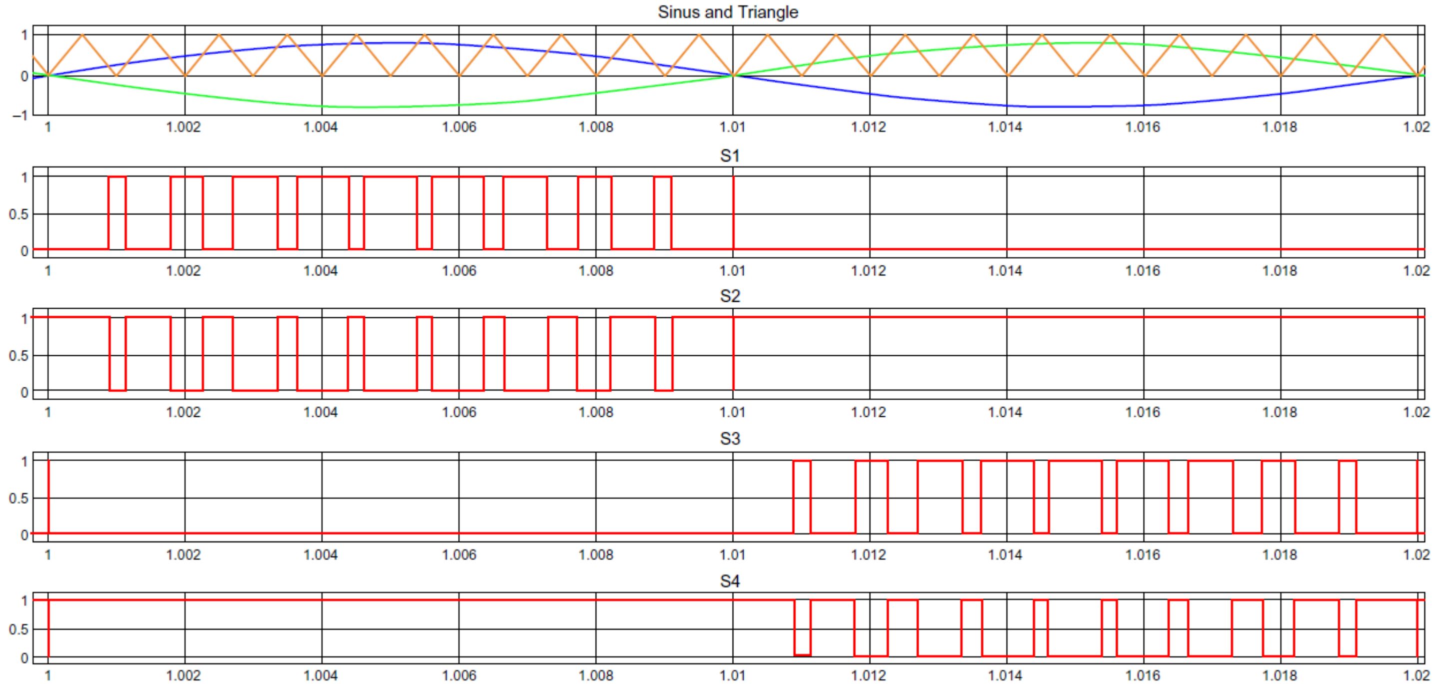




Switching state	"ON" state switches	"OFF" state switches	V_{out}
Positive half-cycle	S_1-S_4	S_2-S_3	$+V_{DC}$
Negative half-cycle	S_2-S_3	S_1-S_4	$-V_{DC}$

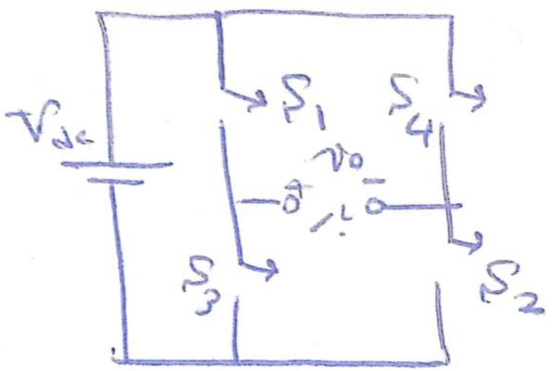
❑ Unipolar SPWM

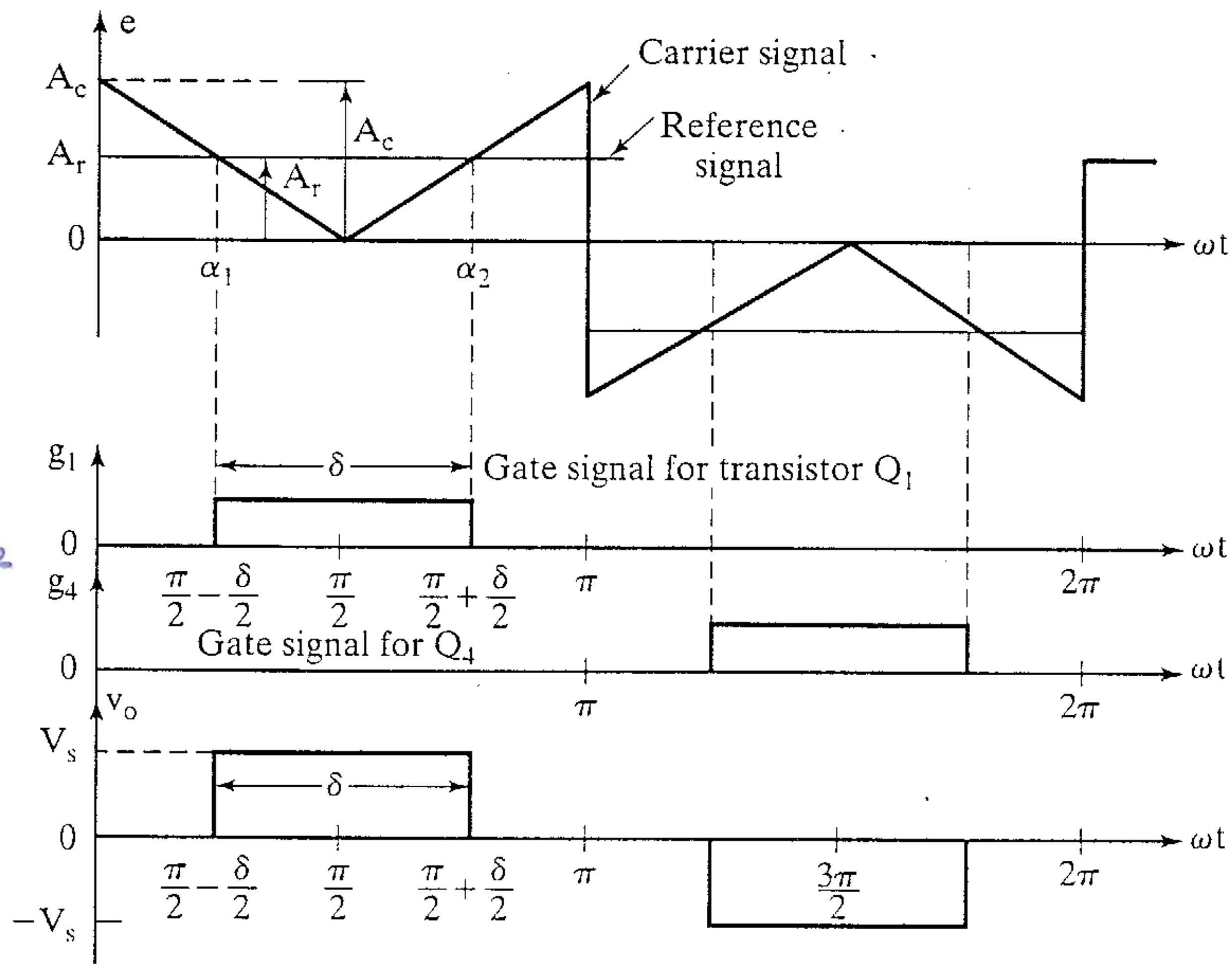




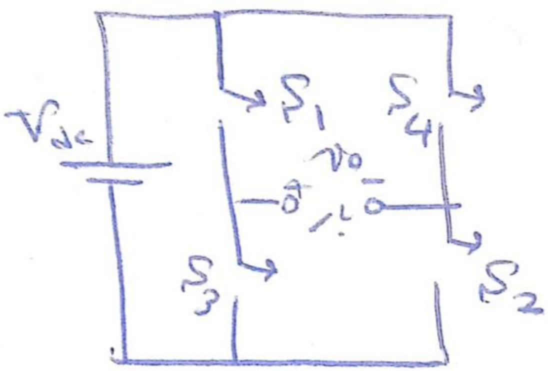
Switching state	"ON" state switches	"OFF" state switches	V_{out}
Positive half-cycle	S_1-S_4	S_2-S_3	$+V_{DC}$
Freewheeling mode-I	S_2-S_4	S_1-S_3	0
Freewheeling mode-II	S_1-S_3	S_2-S_4	0
Negative half-cycle	S_2-S_3	S_1-S_4	$-V_{DC}$

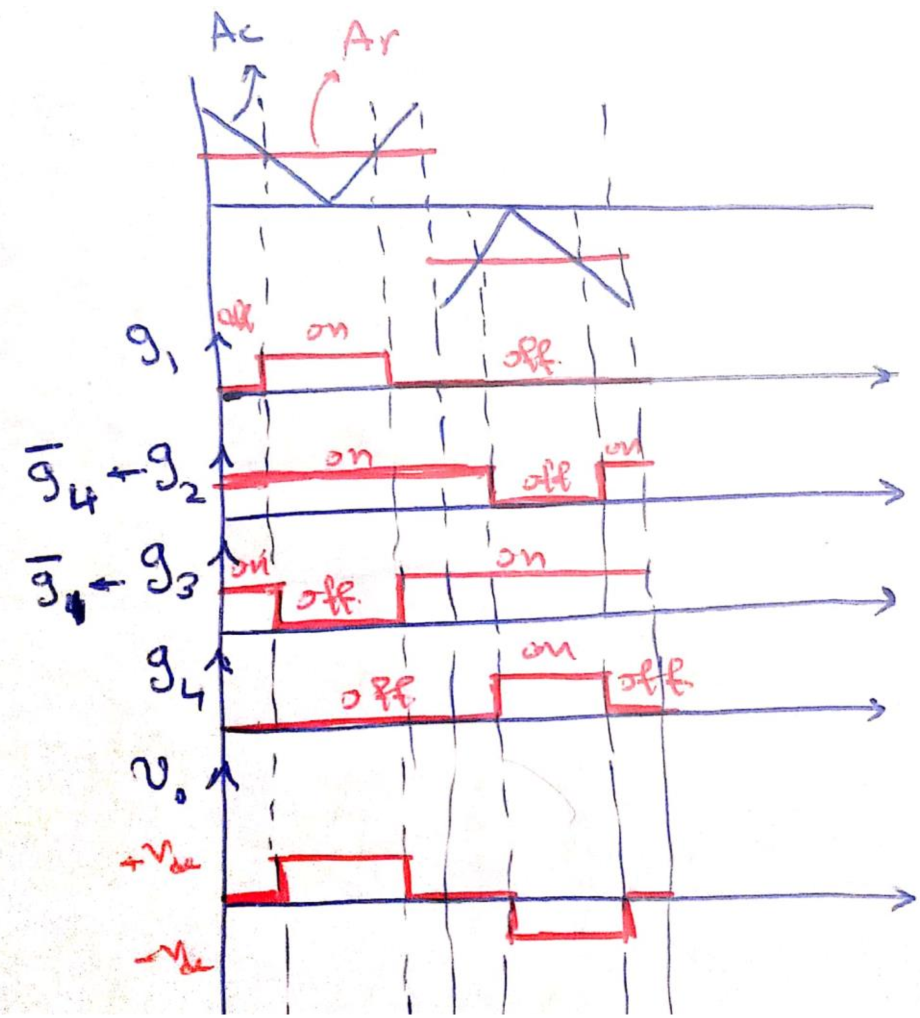
Single-Pulse-Width-Modulation



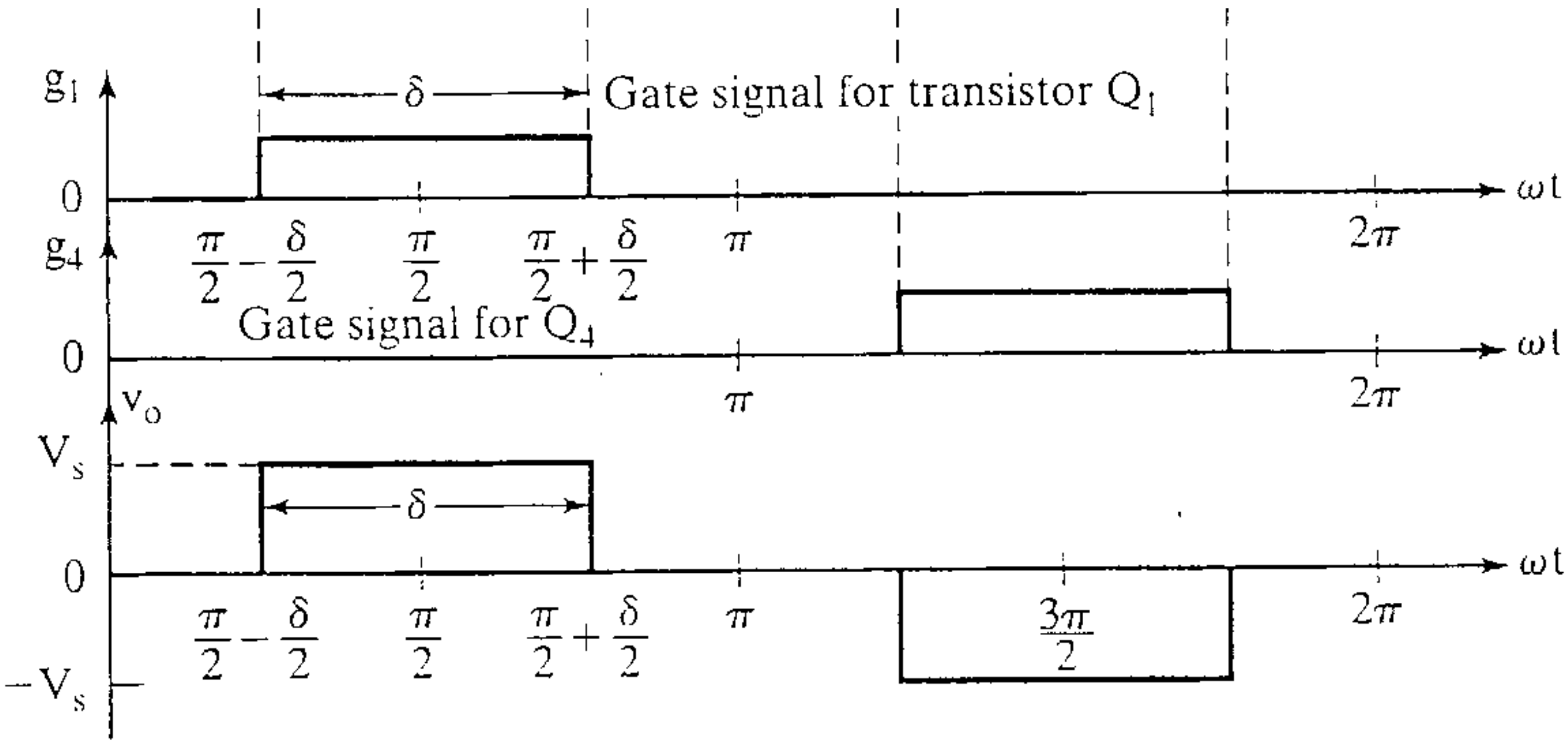


Single-Pulse-Width-Modulation

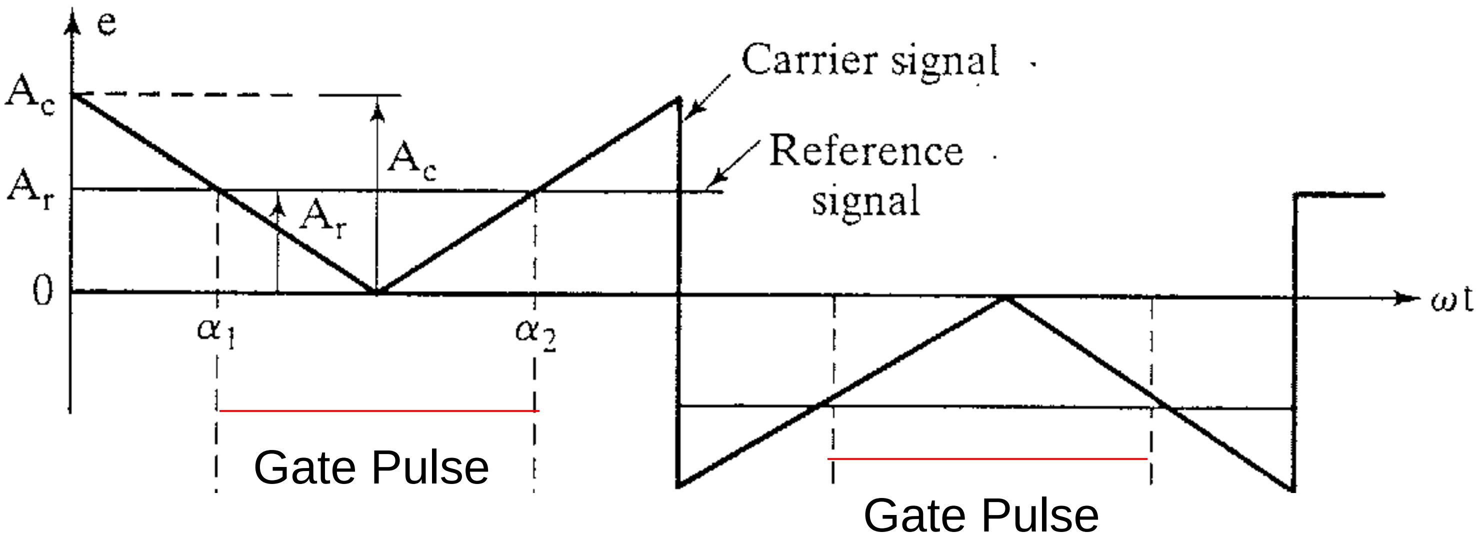




One Pulse per Half-Cycle
Pulse Width Controls the Output Voltage

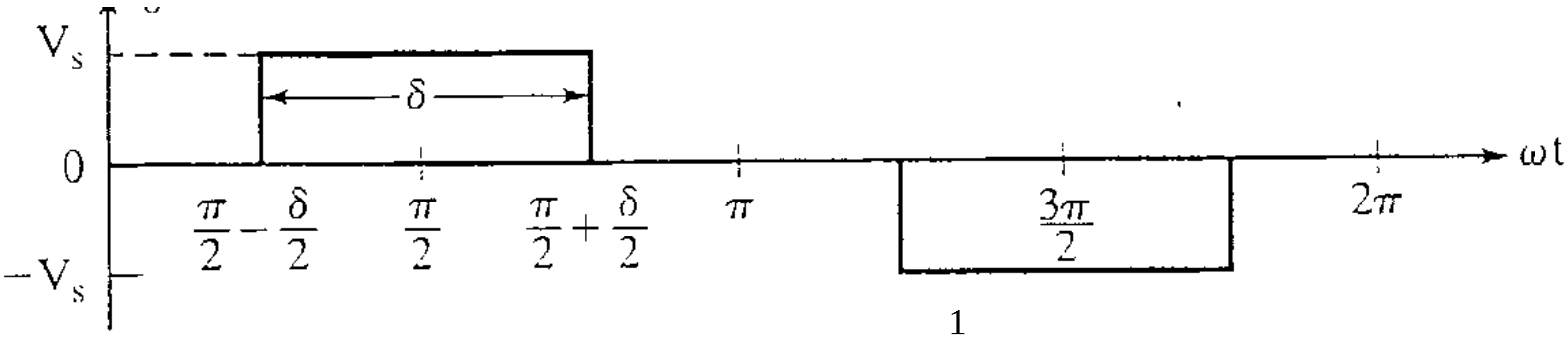


Carrier and Reference Signals



- Compare the Reference Signal with the Carrier
- Frequency of the Reference Signal determines the frequency of the Output Voltage
- Modulation Index = M = A_r/A_c

rms value of the Output Voltage



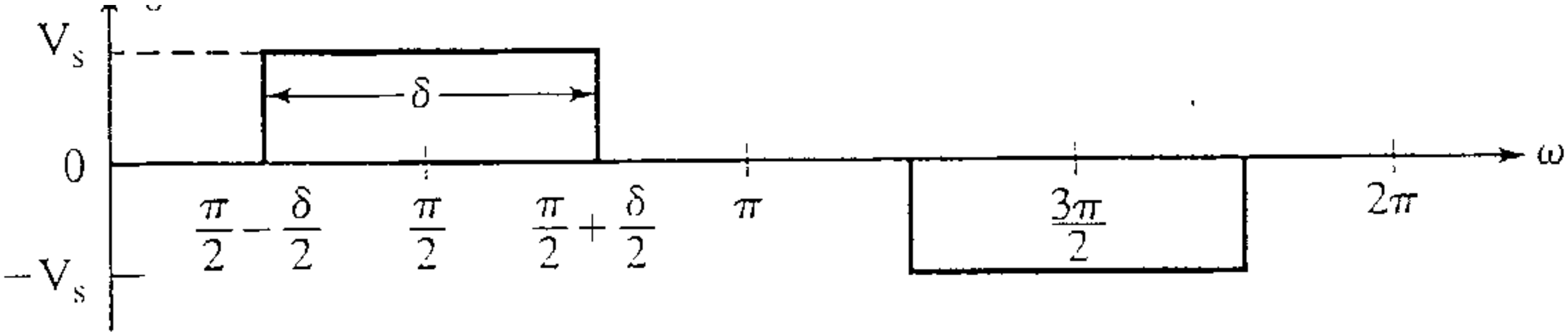
$$V_o = \left[\frac{2}{2\pi} \int_{\frac{\pi-\delta}{2}}^{\frac{\pi+\delta}{2}} V_s^2 d(\omega t) \right]^{\frac{1}{2}}$$

$$V_o = V_s \sqrt{\frac{\delta}{\pi}}$$

$$0^\circ \le \delta \le 180^\circ$$

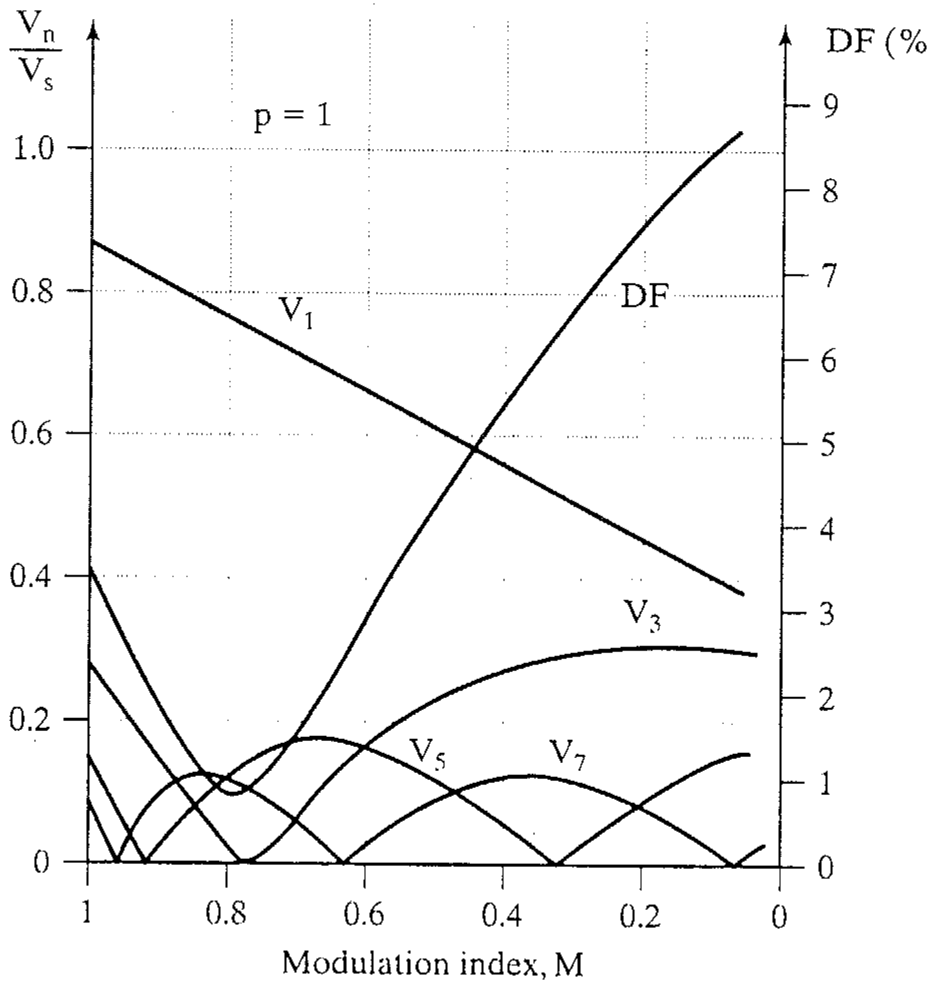
$$0 \le V_o \le V_s$$

Fourier Series for the Output Voltage

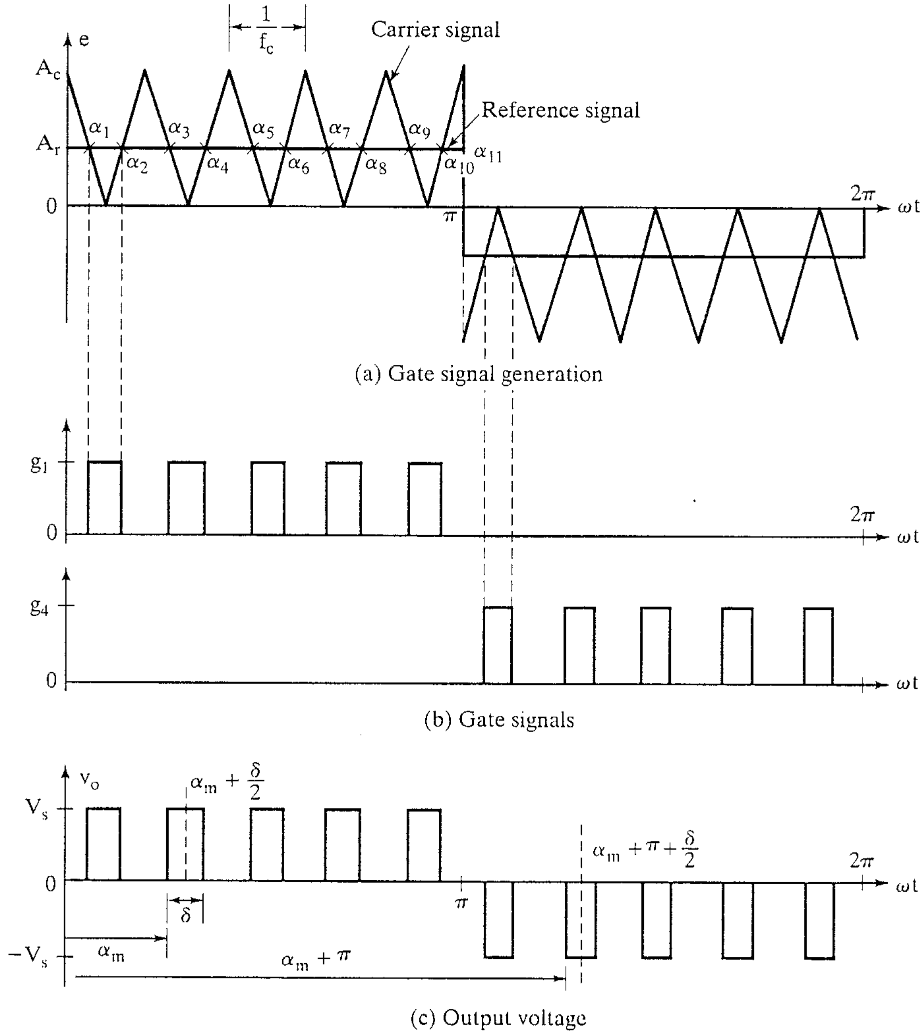


$$v_o(t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_s}{n\pi} \sin\frac{n\delta}{2} \sin n\omega t$$

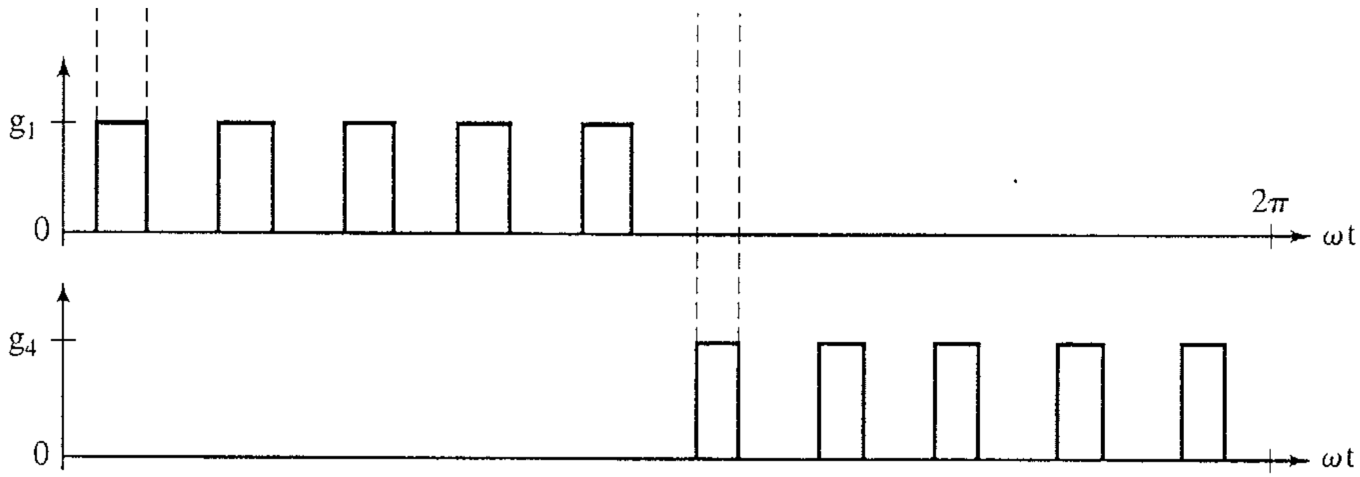
Harmonic Profile



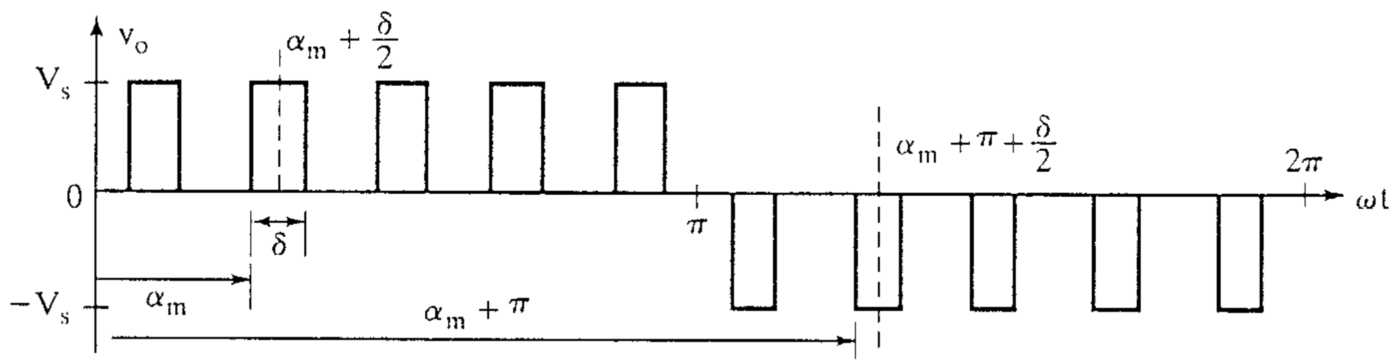
Multiple-Pulse-Width-Modulation



Multiple Pulses per Half-Cycle of Output Voltage

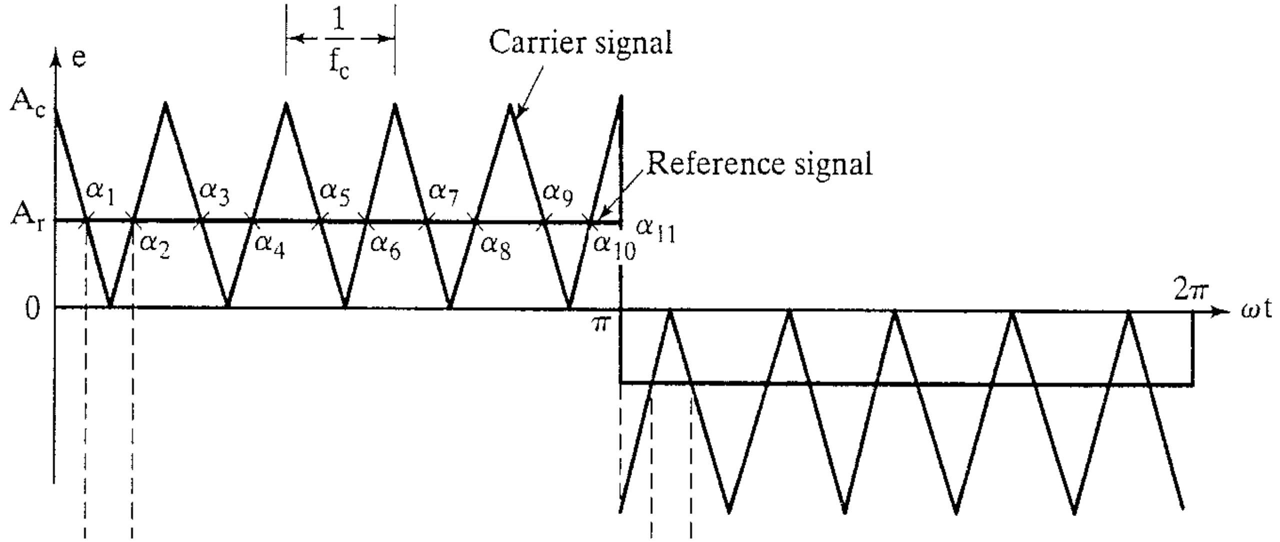


(b) Gate signals



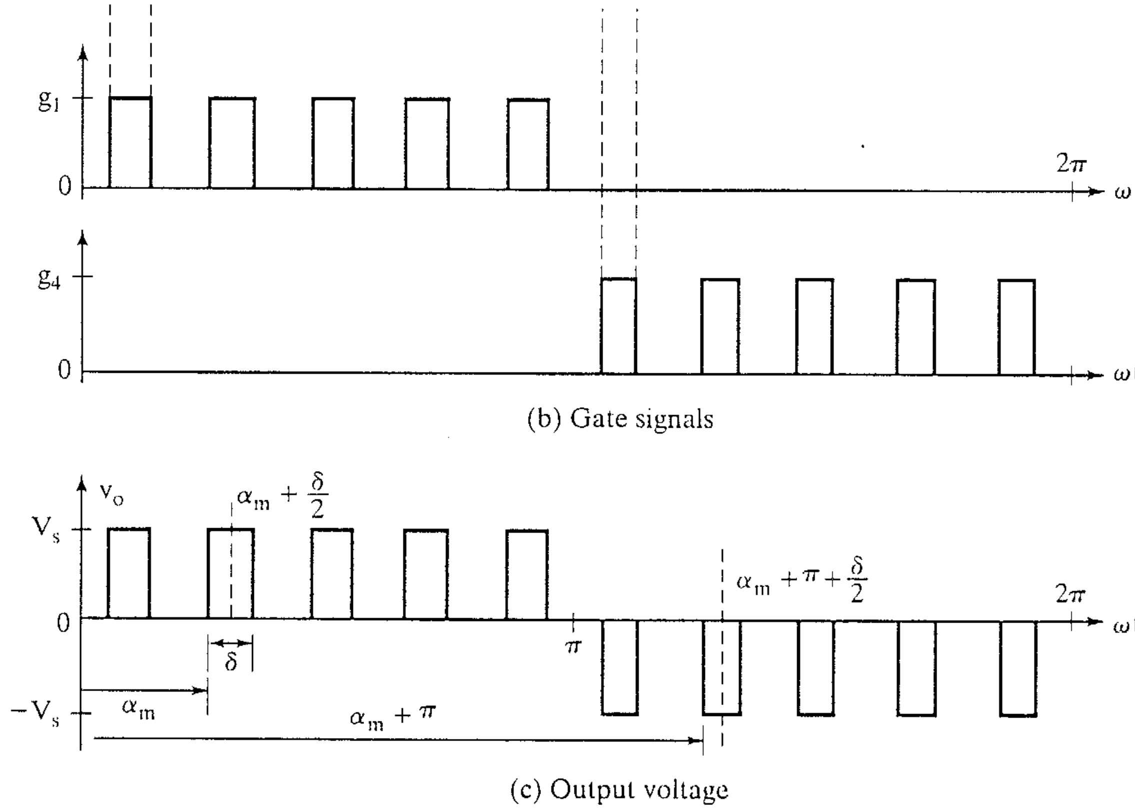
(c) Output voltage

Gate Signal Generation



- Compare the Reference Signal with the Carrier
- Frequency of the Reference Signal determines the Output Voltage Frequency
- Frequency of the Carrier determines the number of pulses per half-cycle
- Modulation Index controls the Output Voltage

Gate Signals and Output Voltage



Number of pulses per half cycle = p = f_c/f_r = m_f

where m_f = frequency modulation ratio

rms Value of the Output Voltage

$$V_o = \left[\frac{2p}{2\pi} \int_{(\frac{\pi}{p}-\delta)/2}^{(\frac{\pi}{p}+\delta)/2} V_s^2 \, d(\omega t) \right]^{\frac{1}{2}}$$

$$\boxed{V_o = V_s \sqrt{\frac{p\delta}{\pi}}}$$

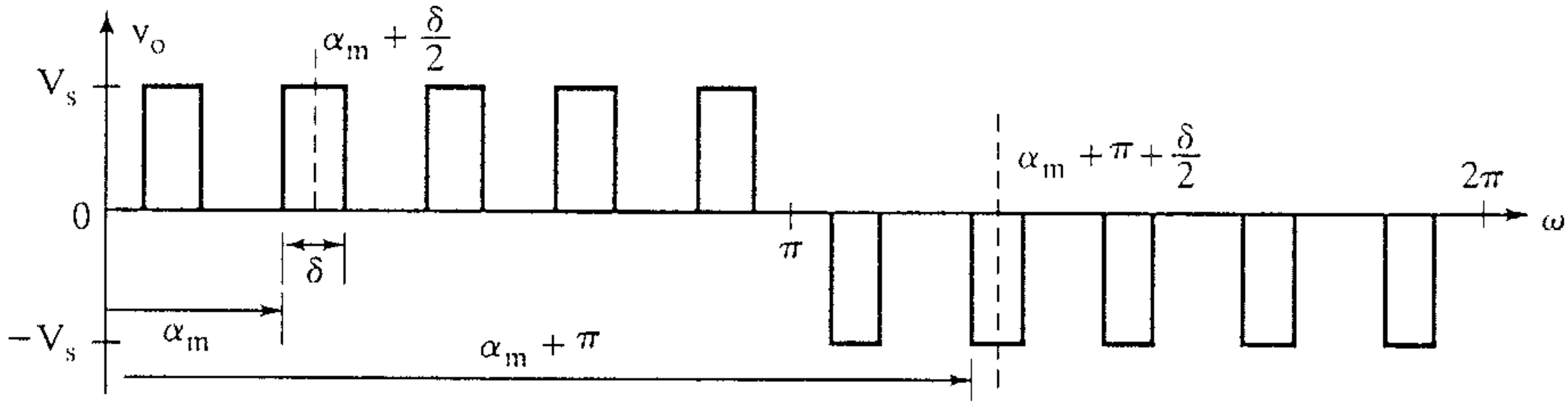
$$0 \le M \le 1$$

$$0 \le \delta \le \frac{T}{2p}$$

$$0 \le \delta \le \frac{\pi}{p}$$

$$0 \le V_o \le V_s$$

Fourier Series of the Output Voltage



$$v_o(t) = \sum_{n=1,3,5,...}^{\infty} B_n \sin n\omega t$$

$$B_n = \sum_{m=1}^{2p} \frac{4V_s}{n\pi} \sin\frac{n\delta}{4}\left[\sin n(\alpha_m + \frac{3\delta}{4}) - \sin n(\pi + \alpha_m + \frac{\delta}{4}\right]$$

Harmonic Profile