AN2637

Power Management Options for LAN78xx

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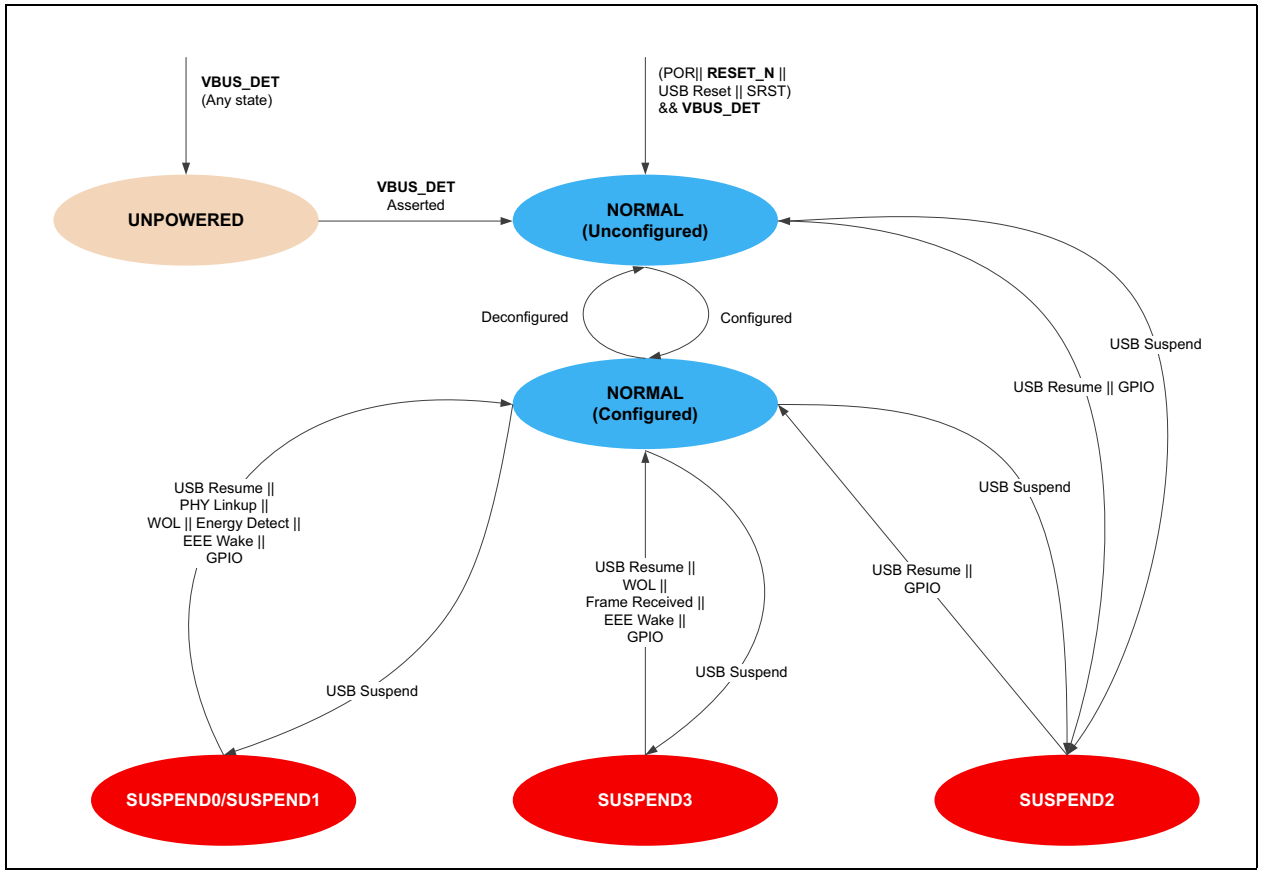
INTRODUCTION

Power management is key to many aspects of product consumption. The ability to enter low power modes enables users to prolong battery life, lower energy costs, and prolong product lifetime. The LAN78xx family has many power management features such as NetDetach, Energy Efficient Ethernet, Enhanced PHY Power Management, Wake-On-LAN (WoL), and Power Management Event Operation. In addition to these features, multiple USB suspend states enable low power consumption when the controlling device is in low-power or sleep mode.

USB POWER STATES

The LAN78xx has seven power states: Unpowered, Normal-Unconfigured, Normal-Configured, SUSPEND0, SUSPEND1, SUSPEND2, and SUSPEND3. Each power state has its own characteristics, especially the SUSPEND states. Figure 1 shows the state diagram for transitions in and out of each state.

FIGURE 1: LAN78XX POWER STATE DIAGRAM



Preconfiguration Power States (Unpowered and Normal-Unconfigured)

The LAN78xx transitions into the Unpowered state when the device is reset and no USB signal (VBUS_DET) is detected. In the Unpowered state, the crystal oscillator and PLLs are off, which puts the device is in its lowest power consumption state.

Once the VBUS_DET signal is asserted on the LAN78xx device, the LAN78xx enters into the Normal-Unconfigured state. The Normal-Unconfigured state only turns on some LAN78xx modules and consumes roughly 1/3 of the power that is consumed in GigE mode in the Normal-Configured power state. The LAN78xx remains in the Normal-Unconfigured state as long as VBUS_DET is asserted and the host has not configured the device via the Set Configuration bit (SetConfiguration wValue = `0`).

For USB 2.0 (Hi-Speed), the Normal-Unconfigured current is 55-65 mA (181-215 mW). For USB 3.1 Gen 1 (Superspeed) on LAN780x, the Normal-Unconfigured current is 75-85 mA (247-281 mW).

Normal-Configured Power State

The device enters the Normal-Configured power state (from Normal-Unconfigured) whenever the EEPROM is loaded, the OTP is loaded, or the device driver configures the device (all set the USB Set Configuration wValue to `1`). In the Normal-Configured state, all of the modules turn on and the LAN78xx is fully operational. Power consumption is at its highest in this state and is highly dependent on the Ethernet speed (GigE highest) and USB mode (SuperSpeed - 3.1 Gen 1 highest). The LAN78xx enters into the Normal-Configured state after a USB Resume signal is sent while in SUSPEND0, SUSPEND1, and SUSPEND3 states.

For USB 2.0 (Hi-Speed), the Normal-Configured current is 200-210 mA (660-693 mW) for 1000BASE-T, 110-120 mA (363-396 mW) for 100BASE-T, and 70-80 mA (231-264 mW) for 10BASE-T. For USB 3.1 Gen 1 (Superspeed) on LAN780x, the Normal-Configured current is 255-265 mA (841-875 mW) for 1000BASE-T, 175-185 mA (577-611 mW) for 100BASE-T, and 135-145 mA (445-479 mW) for 10BASE-T.

SUSPEND0/SUSPEND1 Power States

SUSPEND0 and SUSPEND1 are logically equivalent in the LAN78xx. When the device enters into these suspend modes, the 25-MHz clock is operational while the PLL is shut down, which saves power against the SUSPEND3 state while giving the ability to resume signaling to the Normal-Configured power state with USB Resume, PHY link up indication (Enhanced PHY mode), Energy Efficient Ethernet Wake, WoL, Energy Detect, and GPIO. A USB Reset sets the LAN78xx to the Normal-Unconfigured state.

For USB 2.0, the current is 75-85 mA (247-281 mW) on 1000BASE-T. For USB 3.1, the current is 90-95 mA (297-314 mW) on 1000BASE-T.

In Windows, the LAN78xx driver GUI (under *Device Manager>Properties*) must have both the **Allow computer to turn off this device to save power** and the **Allow this device to wake the computer** options selected.

In Linux, the system is suspended with a system suspend. Prior to the system suspend, the WoL parameters should be set with ethtool (`ethtool -s <device name> wol <Wake-On-LAN parameters>`, where `<device name>` is the LAN78xx Ethernet interface and `<Wake-On-LAN parameters>` are the WoL parameters for the interface).

Register settings to select the SUSPEND0 or SUSPEND1 state prior to USB Suspend:

- SUSPEND0

R/W	Register	Value		
W	014	4180h	//	Sets to SUSPEND0 state
W	084	00001ff0h	//	Sets the device to enable and initiate U1 and U2 states
W	080	40768164h	//	Disables suspend and sets to SuperSpeed mode (40760164 for High-Speed)
W	080	60768164h	//	Enables suspend and sets to SuperSpeed mode (60760164 for High-Speed)

- SUSPEND1

R/W	Register	Value		
W	014	41A0h	//	Sets to SUSPEND1 state
W	084	00001ff0h	//	Sets the device to enable and initiate U1 and U2 states
W	080	40768164h	//	Disables suspend and sets to SuperSpeed mode (40760164 for High-Speed)
W	080	60768164h	//	Enables suspend and sets to SuperSpeed mode (60760164 for High-Speed)

SUSPEND2 Power State

SUSPEND2 is the default suspend state and the only suspend state that the LAN78xx can enter if previously in Normal-Unconfigured state. In the SUSPEND2 state, the LAN78xx PLLs, the 25-MHz clock, and the Ethernet PHY are turned off to achieve the lowest power consuming suspend state. Only USB Resume or GPIO can wake up the device, and the LAN78xx enters the device's previous Normal state upon waking up (Normal-Unconfigured or Normal-Configured). If the returning state upon wake-up is Normal-Unconfigured, the LAN78xx must be configured to enter into the Normal-Configured operation. The current consumption is less than 5 mA (16mW).

In Windows, the LAN78xx driver GUI (under *Device Manager>Properties*) must have the **Allow computer to turn off this device to save power** option selected and the **Allow this device to wake the computer** option unselected.

In Linux, the system is suspended in this mode when either the system is in hibernation or the interface is taken down (`ifconfig <device name> down`, where *<device name>* is the LAN78xx Ethernet interface).

Register settings to select the SUSPEND2 state prior to a USB Suspend:

R/W	Register	Value		
W	014	41C0h	//	Sets to SUSPEND2 state
W	084	00001ff0h	//	Sets the device to enable and initiate U1 and U2 states
W	080	40768164h	//	Disables suspend and sets to SuperSpeed mode (40760164 for High-Speed)
W	080	60768164h	//	Enables suspend and sets to SuperSpeed mode (60760164 for High-Speed)

SUSPEND3 Power State

When the device enters into the SUSPEND3 state, the 25-MHz clock and PLL are on and the power consumption is similar to the Normal-Configured state for this reason. The main functions of the SUSPEND3 state versus the other SUSPEND states are the Always On, Always Connected support, and the Wake Event storage. In the SUSPEND3 state, the LAN78xx can resume signaling to the Normal-Configured power state with the same methods in SUSPEND0 and SUSPEND1. A USB Reset sets the LAN78xx to the Normal-Unconfigured state. The LAN78xx in the SUSPEND3 state consumes roughly 10-20 mA (33-66 mW) less than in the Normal-Configured power state.

In Windows, the LAN78xx driver GUI (under *Device Manager>Properties*) must have both the **Allow computer to turn off this device to save power** and the **Allow this device to wake the computer** options selected.

In Linux, the system is suspended with an auto-suspend that must be supported by the host system. Navigate to the `/sys/bus/usb/devices/<lan78xx_interface>/power/` directory. To set auto-suspend for 2 seconds, use the following commands:

```
echo auto > /sys/bus/usb/devices/<lan78xx_interface>/power/control
echo 2 > /sys/bus/usb/devices/<lan78xx_interface>/power/autosuspend
```

Register settings to select the SUSPEND3 state prior to a USB Suspend:

R/W	Register	Value		
W	014	41E0h	//	Sets to SUSPEND3 state
W	080	40768164h	//	Disable suspend and sets to SuperSpeed mode (40760164 for High-Speed)
W	080	60768164h	//	Enables suspend and sets to SuperSpeed mode (60760164 for High-Speed)

ETHERNET POWER MANAGEMENT

The LAN78xx has many power management modes and features: Energy Efficient Ethernet, Enhanced PHY Power Management mode, NetDetach, Power Management Event (PME) operation, and Wake-On-LAN.

Energy Efficient Ethernet

Energy Efficient Ethernet enables lower power usage when the physical link is not transmitting data. When the link is idle, the Ethernet PHY sends out low power idle signals to maintain link with the device's link partner. The power savings is most beneficial for Gigabit Ethernet links where traffic is sent and received in bursts while maintaining full USB capability. While the link partner is inactive, the device enters into a near suspend state operation. Once the link partner is active, an Energy Efficient Ethernet Wake command is issued to return the device to the Normal-Configured state. Because the inactivity state is based on the suspend state selected (other than SUSPEND2), the device should be configured for either SUSPEND0 or SUSPEND1 as there is almost no power savings running Energy Efficient Ethernet with SUSPEND3 as the configured suspend state.

In Linux, Energy Efficient Ethernet is enabled with the following commands:

`ethtool --set-eee <device_interface> eee on` (where `<device_interface>` is the LAN78xx Ethernet interface)

`ethtool --set-eee <device_interface> advertise 100` (sets Energy Efficient Ethernet to advertise 100BASE-T/Full on the LAN78xx)

`ethtool --set-eee <device_interface> advertise 1000` (sets Energy Efficient Ethernet to advertise 1000BASE-T/Full on the LAN78xx)

Energy Efficient Ethernet is more beneficial than the Enhanced PHY Power Management mode when a switch connects the link partner and the device's Ethernet PHY. The reason is the link to the device's Ethernet PHY is still up when the link partner might be down, which does not trigger the LAN78xx's Ethernet PHY power-down feature of the Enhanced PHY Power Management.

For USB 2.0 with traffic, Energy Efficient Ethernet current consumption is 200-210 mA(660-693 mW) for 1000BASE-T, 100-110 mA (330-363 mW) for 100BASE-T, and 70-80 mA (231-264 mW) for 10BASE-T. For USB 2.0 without traffic, Energy Efficient Ethernet current consumption is 75-85 mA (247-281 mW) for both 1000BASE-T and 100BASE-T, and 50-60 mA (165-198 mW) for 10BASE-T.

On USB 3.1 Gen 1 on LAN780x, Device U2 Initiation Enable must be enabled for best power savings with Energy Efficient Ethernet (bit 12 of register 084h) because the Device U2 Initiation Enable function is disabled by default. For USB 3.1 Gen 1 with traffic and USB suspended to state SUSPEND0/SUSPEND1, Energy Efficient Ethernet current consumption is 210-220 mA (693-726 mW) for 1000BASE-T, 90-105 mA (297-347 mW) for 100BASE-T, and 65-75 mA (215-249 mW) for 10BASE-T. For USB 3.1 Gen 1 without traffic and USB suspended to state SUSPEND0/SUSPEND1, Energy Efficient Ethernet current consumption is 90-95mA (297-314 mW) for 1000BASE-T, 70-80 mA (231-264 mW) for 100BASE-T, and 50-60 mA (165-198 mW) for 10BASE-T.

Note: The Energy Efficient Ethernet feature is not operational when the link partner does not support the IEEE 802.3az standard. In these cases, the LAN78xx uses the same power as in the Normal-Configured state, even when the link is not transmitting data.

Register settings recommended for Energy Efficient Ethernet (using SUSPEND0):

R/W	Register	Value		
W	014	4180h	//	Sets to SUSPEND0 state
W	084	00001ff0h	//	Sets the device to enable and initiate U1 and U2 states
W	080	40768164h	//	Disables suspend and sets to SuperSpeed mode (40760164 for High-Speed)
W	080	60768164h	//	Enables suspend and sets to SuperSpeed mode (60760164 for High-Speed)
W	080	000A3802h	//	Sets Energy Efficient Ethernet

Enhanced PHY Power Management

Enhanced PHY Power Management is used to conserve power on the LAN78xx PHY when the link is down on either end. Once the PHY detects the link is down (either on the PHY end or the link partner end), the PHY is powered down while maintaining USB power. The Enhanced PHY Power Management feature can be used with all SUSPEND states (except SUSPEND2) and can be used in conjunction with NetDetach and PME. For this reason, Enhanced PHY Power Management is recommended for operation in any state (with the exception of Energy Efficient Ethernet) as a power saving function without disrupting communication from the host to the device.

The recommended device setup while using the Enhanced PHY Power Management feature is for the LAN78xx Ethernet PHY to be directly connected to the link partner and not to the link partner through a switch. The reason is if the link partner is down, the LAN78xx Ethernet PHY will still see the link to the switch as active and will not power down the Ethernet PHY. A switch can be used between the LAN78xx Ethernet PHY and the link partner, but the Enhanced PHY Power Management feature is not activated on the device as a user might expect.

When the link is up, the power consumption is similar to the Normal-Configured mode (or SUSPEND0/SUSPEND1/SUSPEND3 if USB is suspended). When the link is down, the LAN78xx only draws 40-50 mA of current (132-165 mW).

Register setting recommended for Enhanced PHY Power Management (note the register is a PHY register):

R/W	PHY Register	Value		
W	01c	a071h	//	Sets to Enhanced PHY Power Management Mode

NetDetach

NetDetach allows the disabling of the device's USB function whenever the Ethernet PHY connection is disabled. This feature gives the host the ability to power down in cases where the USB is still active when the Ethernet is down. The power savings comes from when the link is down, as the device goes into a current draw of about 45-55 mA (148-182 mW).

The "NetDetach" section of the LAN78xx data sheet details the process to use this feature. A host device driver must detect the link is lost, and then detach the USB from the host device. Once the link is up, the host device driver is loaded and the device is configured with the default settings in the driver. In addition, a GPIO wake is issued as another way to wake up the device.

The host driver must do the following (this can be done with the 7800WinCmd command tool) once the Ethernet link is down:

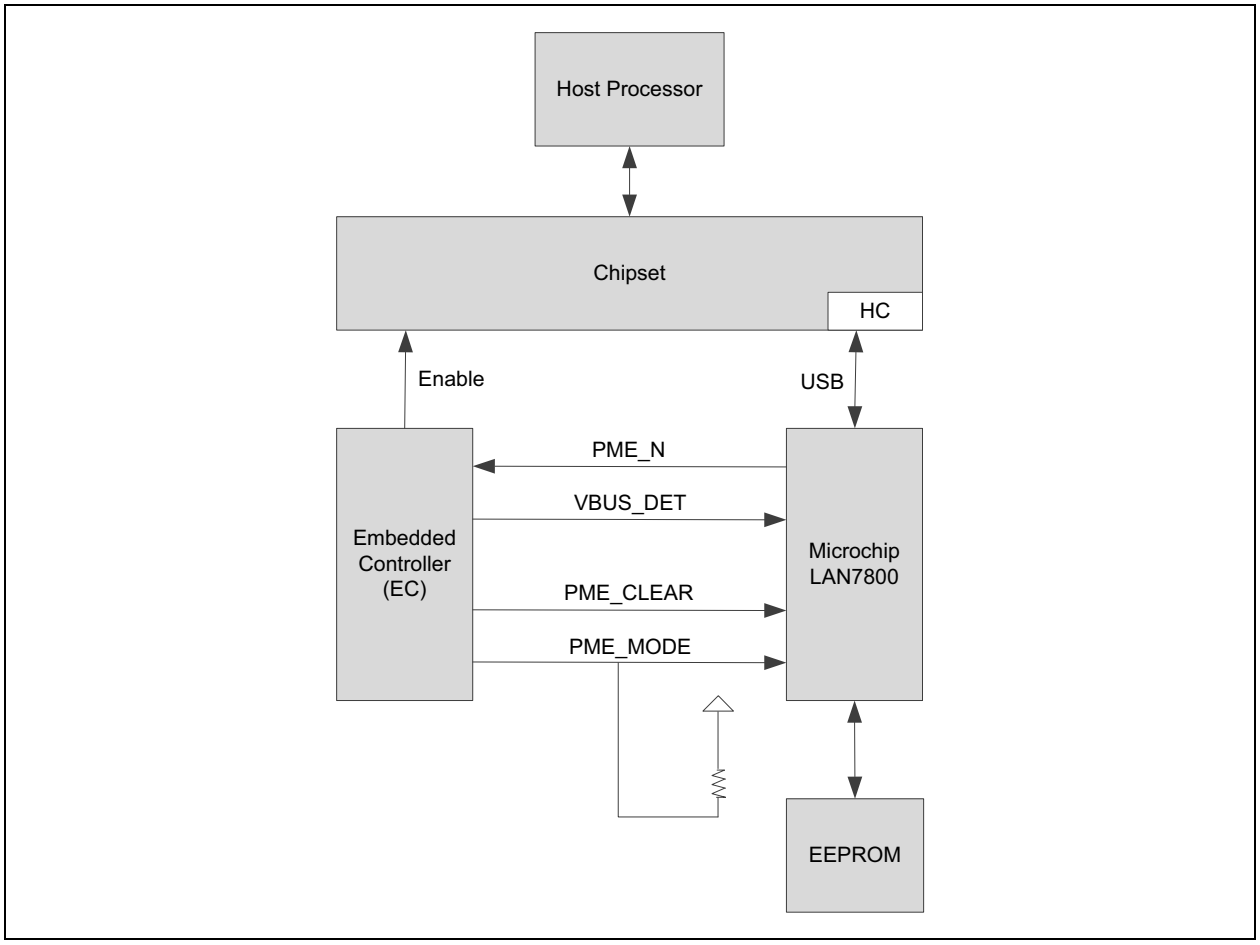
1. Read Register 00Ch for bit 17. If the value is `1`, the PHY_INT has been issued, indicating the Ethernet PHY link is down.
2. Write `1b` to Register 00Ch bit 17 to clear the PHY_INT.
3. Write `1b` to Register 010h bit 14 to enable NetDetach. The device detaches the USB and enters a low current state.
4. Once the link is up, the device reattaches and the driver is loaded.

Power Management Event (PME) Operation

Power Management Event (PME) operation allows the device to send a wake-up signal (via PME_N) to the embedded controller (EC), which then wakes up the host processor that then configures the device for normal operation. For PME operation, an EEPROM/OTP is necessary for the LAN78xx unless the device is configured for wake-up prior to the host processor and chipset powering down.

The process is detailed in Figure 2. When the host processor and the chipset power down, the EC deasserts VBUS_DET to the device and the USB is detached from the device. The device looks for GPIO Wake, a Wake-On-LAN event, or a PHY Link change (depending on which is configured). Once the device detects a wake event, the device asserts PME_N (set to `0`). The EC detects this and wakes the host processor or chipset. The EC then asserts VBUS_DET to the device. The EC also deasserts PME_N (sets to `1`) and asserts PME_CLEAR (sets to `0`). The EEPROM/OTP configuration is loaded to the device. After the configuration is loaded, the device deasserts PME_CLEAR and the device USB connects to the host processor or chipset USB.

FIGURE 2: POWER MANAGEMENT EVENT DIAGRAM



Wake-On-LAN (WoL)

Wake-On-LAN enables the device to wake up the host with a particular packet. The type of packets supported for the WoL function are Magic Packets, Perfect DA Frame, Broadcast Packet, Wakeup Frame, IPv4 TCP SYN, and IPv6 TCP SYN. The power consumed in WoL state on power down is equivalent to the SUSPEND state entered (SUSPEND0, SUSPEND1, or SUSPEND3). The power consumed on host wake-up is similar to Normal-Configured mode.

For all WoL conditions, registers must be written before enabling the type of wake-up packet to initiate WoL. The following registers enable WoL and clear all WoL frame detection status bits.

R/W	Register	Value		
W	014	0004h	//	Enables Wake On LAN (Note: Also sets device to suspend in SUSPEND0)
W	140	00002AF0h	//	Clears Wake Indicators in Wakeup Control and Status Register 1
W	600	000000F0h	//	Clears Wake Indicators in Wakeup Control and Status Register 2

To enable all WoL events:

R/W	Register	Value		
W	140	0000000Fh	//	Enables Perfect DA, Wakeup Frame, Magic Packet and Broadcast WoL
W	600	00000003h	//	Enables IPv4 TCP SYN and IPv6 TCP SYN WoL

The host is then in low power until the device detects a wake-up packet, which wakes up the host. The host then sends a resume signaling to the device, and the device returns to the Normal-Configured state.

For Magic Packet, the device wakes up when a packet is detected that has 6 bytes of `FF` followed by 16 repetitions of the MAC address of the device. To enable wake-up based on Magic Packet, set the following registers:

R/W	Register	Value		
W	140	00000002h	//	Enables Magic Packet WoL
W	600	00000000h	//	Disables IPv4 TCP SYN and IPv6 TCP SYN WoL

For Perfect DA Frame, the device wakes up when a packet is detected with a destination MAC address equivalent to the MAC address in the MAC Receive Address High Register and the MAC Receive Address Low Register. The following sets the Perfect DA Frame WoL:

R/W	Register	Value		
W	140	00000008h	//	Enables Perfect DA Detection WoL
W	600	00000000h	//	Disables IPv4 TCP SYN and IPv6 TCP SYN WoL

For Broadcast Frame WoL, the device wakes up when a packet is detected with a destination MAC address of `FF FF FF FF FF FF`. The following sets the Broadcast Frame WoL:

R/W	Register	Value		
W	140	00000001h	//	Enables Broadcast Frame WoL
W	600	00000000h	//	Disables IPv4 TCP SYN and IPv6 TCP SYN WoL

For Wakeup Frame, 32 filters can be used to check for a wake-up packet and the packet offset to start checking based on the Wakeup Filter X Configuration Registers and the Wakeup Filter X Byte Mask Registers (see the “Wakeup Frame Detection” section of the LAN78xx data sheet for more information). Once those are set, the following sets the Wakeup Frame WoL:

R/W	Register	Value		
W	140	00000004h	//	Enables Wakeup Frame WoL
W	600	00000000h	//	Disables IPv4 TCP SYN and IPv6 TCP SYN WoL

For IPv4 TCP SYN WoL, a TCP packet that has the SYN bit set to `1` and has the MAC address of the device, a multicast address, or a broadcast address can trigger a WoL event. If the SYN IPv4 SYN Destination Address Register, the SYN IPv4 SYN Source Address Register, and the SYN IPv4 TCP Ports Register are all default (that is, all zeros), they yield a match for the WoL event.

The following sets the IPv4 TCP SYN WoL configuration for a source address of 192.168.1.15, a destination address of 192.168.2.1, a source port of 8001, and a destination port of 8201:

R/W	Register	Value		
W	140	00000000h	//	Disables Perfect DA, Wakeup Frame, Magic Packet and Broadcast WoL
W	600	00000001h	//	Enables IPv4 TCP SYN and Disables IPv6 TCP SYN WoL
W	690	C0A8010Fh	//	Sets SYN IPv4 TCP Source Address to 192.168.1.15
W	694	C0A80201h	//	Sets SYN IPv4 TCP Destination Address to 192.168.2.1
W	698	20091F41h	//	Sets SYN IPv4 TCP Dest Port to 8201, sets SYN IPv4 TCP Source Port to 8001

For IPv6 TCP SYN WoL, a TCP packet that has the SYN bit set to `1` and has the MAC address of the device, a multicast address, or a broadcast address can trigger a WoL event. If the SYN IPv6 SYN Destination Address Register, the SYN IPv6 SYN Source Address Register, and the SYN IPv6 TCP Ports Register are all default (that is, all zeros), they yield a match for the WoL event.

The following sets the IPv6 TCP SYN WoL configuration for a source address of 2201:AB45:C454:1234:1234:5678:1341:1238, destination address of 2201:AB45::254B:C421, a source port of 8001, and a destination port of 8201:

R/W	Register	Value		
W	140	00000000h	//	Disables Perfect DA, Wakeup Frame, Magic Packet and Broadcast WoL
W	600	00000002h	//	Enables IPv6 TCP SYN and Disables IPv4 TCP SYN WoL
W	69C	13411238h	//	Sets SYN IPv6 TCP Source Address to 2201:AB45:C454:1234:1234:5678:1341:1238 Bits [31:0]
W	6A0	12345678h	//	Sets SYN IPv6 TCP Source Address to 2201:AB45:C454:1234:1234:5678:1341:1238 Bits [63:32]
W	6A4	C4541234h	//	Sets SYN IPv6 TCP Source Address to 2201:AB45:C454:1234:1234:5678:1341:1238 Bits [95:64]
W	6A8	2201AB45h	//	Sets SYN IPv6 TCP Source Address to 2201:AB45:C454:1234:1234:5678:1341:1238 Bits [127:96]
W	6AC	254BC421h	//	Sets SYN IPv6 TCP Destination Address to 2201:AB45::254B:C421 Bits [31:0]
W	6B0	00000000h	//	Sets SYN IPv6 TCP Destination Address to 2201:AB45::254B:C421 Bits [63:32]
W	6B4	00000000h	//	Sets SYN IPv6 TCP Destination Address to 2201:AB45::254B:C421 Bits [95:64]
W	6B8	2201AB45h	//	Sets SYN IPv6 TCP Destination Address to 2201:AB45::254B:C421 Bits [127:96]
W	6BC	20091F41h	//	Sets SYN IPv6 TCP Dest Port to 8201, sets SYN IPv6 TCP Source Port to 8001

RECOMMENDED SETUPS FOR LOWEST POWER CONSUMPTION

No PME: Use EEE, USB Suspend to SUSPEND0/SUSPEND1 state with Device U2 Initiation enabled if at SuperSpeed (USB 3.1 Gen 1). If not running at Gigabit Ethernet, either set to 100BASE-T/10BASE-T or set to auto-negotiate with 1000BASE-T not advertised.

PME: Use EEE, USB Suspend (GPIO pins are necessary if using the SUSPEND2 state for GPIO wake), and operate at HS (USB 2.0). Enable WoL events. If not running at Gigabit Ethernet, either set to 100BASE-T/10BASE-T or set to auto-negotiate with 1000BASE-T not advertised.

APPENDIX A: REVISION HISTORY

TABLE A-1: REVISION HISTORY

Revision	Section/Figure/Entry	Correction
DS00002637A (02-17-18)	Initial release	

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Malaysia - Penang
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Philippines - Manila
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Taiwan - Hsin Chu
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