Using this method implies that you have a solid understanding of the following table:

# Reference Table

Remember, subnetting involves the "borrowing" of consecutive bits from left to right; starting from the Greatest Significant Bit.

| Decimal | 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
|---|---|---|---|---|---|---|---|---|
| Base Value | $2^7$ | $2^6$ | $2^5$ | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ |
| Borrowed Bits | +1 | +2 | +3 | +4 | +5 | +6 | +7 | +8 |
| Borrowed bits in binary | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Total | 128 | 192 | 224 | 240 | 248 | 252 | 254 | 255 |

## Key Concepts to remember:

### Subnetting

- the process of dividing a large network into smaller networks; aka "borrowing" bits from the host portion and allocating them to the network portion. Refer to the borrowed bits section above.

### Subnet Mask

- A subnet mask is a 32-bit number associated with an ip address that identifies the network and host portions (ID) of an ip address. Each bit that is turned on [1] is a part of the network portion; whereas, each bit that is turned off [0] is a part of the host portion.
- Class A: 255.0.0.0
- Subnet mask in binary: 11111111.00000000.00000000.00000000
- Class B: 255.255.0.0
- Subnet mask in binary: 11111111.11111111.00000000.00000000
- Class C: 255.255.255.0
- Subnet mask in binary: 11111111.11111111.11111111.00000000

### Classes of IP addresses

- A value of 1-126: Type A, Default Subnet mask = 255.0.0.0 or /8 in CIDR Notation

- A value of 128-191: Type B, Default Subnet mask = 255.255.0.0 or /16 in CIDR Notation
- A value of 192-223: Type C Default Subnet mask = 255.255.255.0 or /24 in CIDR Notation

## Private IP Address Ranges

- Type A Private IP Address: [10.0.0.0 - 10.255.255.255] /8
- Type B Private IP Address: [172.16.0.0 - 172.31.255.255] /16
- Type C Private IP Address: [192.168.0.0 - 192.168.255.255] /24

## CIDR Notation

- Classless Interdomain Routing (CIDR) notation represents the number of network bits as a / followed by the number of bits that are “turned on” [1].
- Referring back to the classes, Type A = /8, Type B = /16, Type C = /24

## Interval or “Magic Number” or LSB [Least Significant Bit]

- The Last network bit that is turned on in the subnet mask.
- With the interval, you can determine the range/total amount of IP addresses within the subnets.

## Classful Addresses

The same process of finding the interval applies to Classful Addresses as well.
Class A: 10.10.10.0/8
Subnet mask in binary: 11111111.00000000.00000000.00000000
The least significant bit aka interval is 1.

Class B: 172.17.4.0/16
Subnet mask in binary: 11111111.11111111.00000000.00000000
The least significant bit aka interval is 1.

Class C: 192.168.1.0/24
Subnet mask in binary: 11111111.11111111.11111111.00000000
The least significant bit aka interval is 1.

You can also view a classful address as being the previous classful address + 8 borrowed bits:
e.g. 192.168.0.0/24 = /16 + /8 borrowed bits

E.g 10.150.211.1 /8
Network address: 10.0.0.0
Broadcast address: 10.255.255.255
Range: 10.0.0.0 - 10.255.255.255

E.g 172.17.33.4/16
Network address: 172.17.0.0
Broadcast address: 172.17.255.255
Range: 172.17.0.0 - 172.17.255.255

### E.g 192.168.3.21/24

Network address: 192.168.3.0
Broadcast address: 192.168.3.255
Range: 192.168.3.0 - 192.168.3.255

### Mixed Octet

- the octet that is going to be manipulated, based off of the CIDR Notation:
- Octet 1 will be dictated by a subnet mask of /1 - /8 ;
  - e.g 10.10.10.1 /8
- Octet 2 will be dictated by a subnet mask of /9 - /16
  - E.g 172.18.3.2/16
- Octet 3 will be dictated by a subnet mask of /17 - /24
  - E.g 192.168.1.0
- Octet 4 will be dictated by a subnet mask of /25 - /32
  - 192.168.6.32

## Formulas

### 1. Total subnets

Total subnets = $2^{bb}$

- where bb = “borrowed bits”

### 2. Total IP addresses

Total IP addresses = $2^{h}\ or\ 2^{32-n}$

- where h = “host bits”, and n = network bits.

### 3. Total Assignable/host IP addresses

Total Assignable IP addresses = $(2^{h} - 2)$

- Remember that there is the network address and a broadcast address in a given range; these addresses are not assignable.
- The network address defines the network.

- The broadcast address identifies each device/IP address on said network.

## Additional Formulas[Optional]

- These formulas can be used in the case that you forget aspects of the table.

### 1. Host bits and Network bits

$h = 32 - n, \ and \, n = 32 - h$

- where h = host bits, n = network bits
- Remember that a subnet mask is composed of two parts: the network portion and the host portion.
- 32 is the total number of bits in an IP address, therefore 32 - one of the portions will result in the other part: 32 - network bits = host bits; 32 - host bits = network bits.

### 2. Borrowed Bits

$bb = n - d$

- where n = network bits, d = the default bits based of the class of the IP address

### 3. Interval or "Magic Number"

$I = 2^{8-bb}, or\ I = 2^{|bb-8|}\ \ [if\ bb\ is\ < 8]$

or

$I = 2^{8-(bb-8)}\ or\ 2^{8-(|8-bb|)}\ \ [if\ bb\ is\ > 8]$

- where I = interval, bb = "borrowed bits",
- The two bars || represents the "absolute value" or a value that will always be positive

a. Meaning

- There are 8 total bits in a subnet mask's octet, when representing this value as a network portion, this equates to 255 in decimal or 11111111 in binary.
- The borrowed bits indicate the amount of bits that were taken from the host portion and given to the network portion.
- If you subtract the network portion from the borrowed bits, this is equal to the range of IP addresses that will be in the given subnet. Furthermore, this value will be the last bit that is turned on in the borrowed bit portion.

e.g /26 in Binary and Decimal

11111111.11111111.11111111.11000000
255. 255. 255. 192

- The second 1 in this case has a decimal value of 64
- Instead of having to do this, you can use the equation.

e.g
192.168.2.65 /26

$I = 2^{|bb-8|}$
$bo = n - d$
$bo = 26 - 24$
$bo = 2$
$I = 2^{|2-8|}$
$I = 2^{6}$
$I = 64$

e.g
172.18.2.1 /26
$I = 2^{|bb-8|}\ [if\ bb < 8]$
$bb = n - d$
$bb = 26 - 16$
$bb = 10,\ 10 > 8$
$I = 2^{8-(|bb-8|)}\ [if\ bb > 8]$
$I = 2^{8-2}$
$I = 2^{6}$
$I = 64$

## Keys to Subnetting Quickly:

### Subnet Association Questions

1. Determine the class of the IP address based on the first octet.
- This ensures that the correct amount of “borrowed bits” are determined.
- This also indicates the default network portion of the IP address.

2. Determine the mixed octet based off of the subnet mask.
- For example, 192.168.3.8 /29

- /29 adheres to the .8 octet
- The mixed octet is the corresponding octet of the IP address that the subnet mask adheres to.
- This is where knowing the table comes in handy.

3. Determine the amount of borrowed bits and host bits based on the CIDR notation.

4. Determine the interval based on the subnet mask .
- Once you know the interval, you will know the range of IP addresses for each subnet.
- E.g. /29 indicates an interval of 8, therefore each subnet will include 8 total IP addresses.

5. Divide the mixed octet by the interval, then multiply the quotient by the interval without the remainder; this gives the starting point (network address) of the range.
- E.g. 192.168.1.129 /30
- $129/4 = 32R1, 32 * 4 = 128$, network address = 192.168.1.128
- Range = network address to next network address - 1
- Range = [192.168.1.128 - 192.168.1.131]

6. Complete the ranges for additional subnets if necessary

7. Create a new subnet for leftover devices if necessary
- Leftover devices include IP addresses that will not be used. These will reside in a separate subnet.

## Subnet/Host Determination Questions

1. Determine the amount of IP addresses
- Total amount of IP addresses = $2^h$, where h = amount of host bits

2. Determine the amount of assignable IP addresses
- Total amount of assignable IP addresses = $2^h - 2$, where h = amount of host bits

3. Determine the amount of subnets
- Total amount of subnets = $2^{borrowed\ bits}$

## Subnetting Class As and Bs

When subnetting Class As & Class Bs, all of the other concepts remain the same, however the network addresses for your ranges will change.

E.g. 172.24.3.0/20
Your interval = 16, /20 in binary = 11111111.11111111.11110000.00000000
Your least significant bit in the 3rd octet is a decimal value of 16.
Also, since the octet that will be manipulated in the subnet mask is the third octet, the octet that will change in the IP address will be the third octet.

But whatever changes you make for your mixed octet must then apply for any octets that follow. Furthermore, the highest value that an octet can be is 255, therefore, the broadcast addresses will always end at 255.

172.24.0.0 - 172.24.15.255
172.24.16.0 - 172.24.31.255
172.24.32.0 - 172.24.47.255

E.g. 10.139.11.0 /11
Your Interval = 32, /11 in binary = 11111111.11100000.00000000.00000000
Your least significant bit in the second octet is a decimal value of 32.

With the interval of 32, you can create your IP address ranges:
10.0.0.0 - 10.31.255.255
10.32.0.0 - 10.63.255.255
10.64.0.0 - 10.91.255.255

# Examples

## A. Subnet Association

### 1. Which subnet does 192.168.59.169/26 belong to?

Step 1: Determine the class of the IP address based on the first octet.
- 192 = Type C IP address, default network bits = /24

Step 2: Determine the mixed octet
- 192.168.59.169 /26

Step 3 : Determine amount of borrowed bits:
- /26 - /24 = 2 borrowed bits

Step 4: Determine the interval based on the subnet mask:
- Interval = $2^{8-b} = 2^{8-2} = 2^{6} = 64$

Step 5: Divide the mixed octet by the interval, then multiply the quotient by the interval without the remainder; this gives the starting point (network address) of the range:

- 169/64 = 2R? 2(64) = 128. Network Address = 192.168.59.128
- Range = 192.168.59.128 to (192.168.59.128 +0.0.0. [64-1]) -- 192.168.59.128 to 192.168.59.191
- 192.168.59.169 falls within the 192.168.59.128 network.

2. What is the broadcast address of the network 172.23.2.0 /23?

Step 1: Determine the class of the IP address based on the first octet.
- 172 = Type B IP address, default network bits = /16

Step 2: Determine the mixed octet
- 172.23.2.0 /23

Step 3 : Determine amount of borrowed bits:
- /23 [network bits] - /16 [default network bits] = 7 borrowed bits

Step 4: Determine the interval based on the subnet mask:
- Interval = $2^{8-b} = 2^{8-7} = 2^{1} = 2$

Step 5: Divide the mixed octet by the interval, then multiply the quotient by the interval without the remainder; this gives the starting point (network address) of the range:

- $2/2 = 1,\ 1 * 2 = 2$, Network Address = 172.23.2.0

- Range = 172.23.2.0 to 172.23.[2+1] .0
  - Keep in mind that this Type B address has another octet after the mixed octet (for the host bits).
  - As a result, the range has to indicate all possible addresses in that octet:
  Range = 172.23.2.0 - 172.23.3.255
  - Broadcast address = The final IP address in the range
  -Broadcast address = 172.23.3.255

## B. Subnet/Host Determination

3. You are designing a subnet mask for the 172.30.0.0 network. You want 2700 subnets with less than 8 hosts on each subnet. What mask should you use?

Step 1: Determine the amount of IP addresses
8 Hosts are needed on each subnet
8 < $2^{4}$, 4 = amount of host bits we need to satisfy the host requirement
32 total bits - 4 Host bits = 28 network bits

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/28, Interval = 16

Total Assignable Ip addresses = $(2^{4\ host\ bits} - 2)$ = 14

Step 2: Determine the subnets

172.30.0.0, the first octet = 172, this falls within the Class B range [128-191]
Default Classful subnet mask = /16
/28 [28 network bits] - /16 [default network bits] = /12 aka we have 12 "borrowed bits"

Total subnets = $2^{borrowed\ bits}$

Total subnets = $2^{12\ borrowed\ bits} = 4096$ subnets

/28 is the mask to use.

4. *You are designing a subnet mask for the 172.18.0.0 network. You want 3200 subnets with at least 9 hosts on each subnet. What subnet mask should you use?*

Step 1: Determine the amount of IP addresses

- $2^h \geq 9$
- $2^4 \geq 9$

At least 4 host bits are required since $2^4 = 16$, this value will satisfy the 9 host requirement:
$32\ total\ bits - 4\ host\ bits = 28\ network\ bits$ aka /28 subnet mask
/28 indicates an interval of 16

Step 2: Determine the amount of subnets

- Total subnets = $2^{borrowed\ bits}$
- $3200 \leq 2^{borrowed\ bits}$
- $2^{12} \geq 3200$
- At least 12 borrowed bits are needed

172.18.0.0, the first octet has a value of 172, this indicates a Class B address since 172 is between the range of [128-191]
The default classful subnet mask of a Class B address = /16
Borrowed bits = New subnet mask - classful subnet mask

Borrowed bits = $/28 - /16$ = /12 aka 12 borrowed bits
/28 is the subnet mask you need

5. *How many subnets and hosts per subnet can you get from the network 172.25.0.0 255.255.255.240?*

Step 1: Determine the class of the IP address based on the first octet

- 172 = Class B IP address, default subnet mask = /16

Step 2: Determine the amount of borrowed bits
- $b = n - d$
- $b = 28 - 16,$ /28 = /24 + 1 [128] + 1[64] + 1[32] + 1[16] = 240
- $b = 12$

Step 3: Determine the amount of subnets
- $total\ subnets = 2^{borrowed\ bits}$
- $total\ subnets = 2^{12}$
- $total\ subnets = 4096$

Step 4: Determine the amount of host addresses
- Assignable IPs = $2^{h} - 2$
- Assignable IPs = $2^{32-28} - 2$
- Assignable IPs = $2^{4} - 2$
- $Assignable\ IPs = 16 - 2 = 14$

## Alternate Subnet Determination

6. What is the subnet mask, first available host address of subnet one (NOT subnet zero), and the maximum number of hosts per subnet for the network below?
You need to allow for the maximum number of hosts. You may be able to use the subnet zero and the all-ones subnet. RFC 1878

Network ID: 121.0.0.0
Subnets Required: 8
Subnet Mask:
?
1st Available Host Address of Subnet 1:
?
Max # of hosts/subnet:
?

Step 1: Determine the class of the IP address in question
- First octet = 121, this indicates a class of Class A [default subnet mask of /8] since 121 is in the range of [1-127]

Step 2: Determine the amount of borrowed bits required to satisfy the subnet requirement, this is based on the total subnets formula.
- Total subnets = $2^{b}$
- Subnets required >= $2^{3\ borrowed\ bits}$

Step 3: Determine the new subnet mask based off the borrowed bits and the class of the IP address

- Default network bits of “8” + borrowed bits of “3” = “11” or /11 subnet mask

Step 4: Determine the interval based on the new subnet mask, this will determine our range of ip addresses

- /11 in decimal is 255.224.0.0,
- /11 in binary is 11111111.11100000.00000000.00000000, this indicates an interval of 32

Step 5: Determine the ranges based on the interval
121.0.0.0:

- 121.0.0.0 - 121.31.255.255 [Subnet 0]
- 121.32.0.0.0 - 121.63.255.255 [Subnet 1]

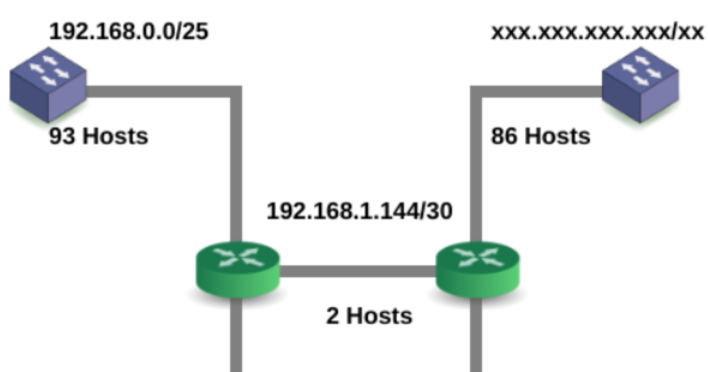
Step 6: Determine the amount of host bits and IP addresses based off of the subnet mask

- $host_{bits} = 32 - network_{bits}$ , $host_{bits} = 32 - 11$, $host_{bits} = 21$
-
- Total IP addresses = $2^{host\ bits}$, $total = 2^{21}$, $total = 2097152$ addresses
- Total assignable [host] addresses = total addresses - 2
- Total assignable = $2097152 - 2$, total assignable = $2097150$ host addresses

Step 7: Fill in the blanks
Network ID: 121.0.0.0
Subnets Required: 8
Subnet Mask:
255.224.0.0
1st Available Host Address of Subnet 1:
121.32.0.1
Max # of hosts/subnet:
2097150

## Topology Related Scenarios

What is the network address and subnet mask (in CIDR notation) of the hidden (xxx.xxx.xxx.xxx/xx) subnet? The whole network has a network address and subnet mask of 192.168.0.0/23



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Step 1: Determine the range for the whole network given the network address and subnet mask.
The whole network has a network address and subnet mask of 192.168.0.0/23
Interval = 2
The range for the whole network is [192.168.0.0 - 192.168.1.255]

Step 2: Determine the ranges for each network given the subnet masks. Start from the network with the greatest hosts and work your way down, continuing the range from the previous network. Be sure to consider the IP addresses of the known hosts/networks as well.
If a network address and subnet mask is unavailable, choose a subnet mask that satisfies the given host requirements.

Network 1: 93 Hosts
192.168.0.0/25: Range = [192.168.0.0 - 192.168.0.127]

Network 2: 86 Hosts
Network address is unavailable; host requirement is 86 hosts,
$2^7 > 86$
7 host bits will satisfy this requirement.

$n = 32 - h, n = 32 - 7, n = 25$, a subnet mask of /25 will be used

The other networks are a part of the 192.168.1.0 network, therefore we can infer that this network will continue from the 192.168.0.0 network.

Previous Network: 192.168.0.0/25; Range = [192.168.0.0 - 192.168.0.127]
Current Network: 192.168.0.128/25; Range = [192.168.0.128 - 192.168.0.255]

### Answer: 192.168.0.128/25

## Subnetting Resources

### Subnet Association Questions

http://www.subnettingquestions.com/

### Address Range Determination

https://www.nybi.org/subnet-2.php

### Alternate Subnet Association Questions

https://www.nybi.org/subnet-1.php

### Topology-related Scenarios

https://subnettingpractice.com/

## Supernetting

Supernetting is the opposite of subnetting, it involves the process of the host portion “borrowing” bits from the network portion. In other words, bits from the network portion will be allocated to the host portion.

#### CIDR

Classless Interdomain Routing is the actual network terminology for supernetting.
Classless inter-domain routing shortens the classful subnet mask. Instead of adding one’s to the subnet mask we remove them.
Classless inter-domain routing summarizes networks by removing subnet bits [from the network portion].

##### Where is CIDR used?

CIDR can be useful for example, service providers. They have to maintain lots and lots of networks in the routing table and instead of advertising each individual route, maybe for each individual customer, they could send an aggregated route. They could send a single network advertisement which could encompass multiple networks.

#### Route Summarization

Route Summarization/Route Aggregation, where routes to multiple networks with similar network prefixes are combined into a single routing entry, with the routing entry pointing to a Super network, encompassing all the networks. This in turn significantly reduces the size of routing tables and also the size of routing updates exchanged by routing protocols. Without Supernetting, routers will share all routes from routing tables as they are. With

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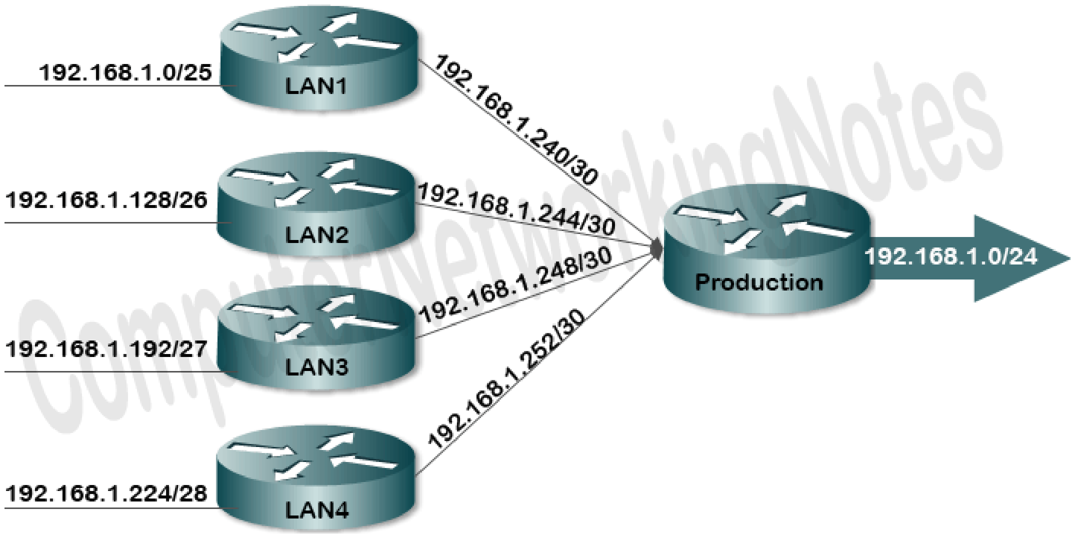
Supernetting, it will summarize them before sharing. Route summarization reduces the size of routing updates dramatically.

The following figure shows an example of Supernetting.




In the above example, 8 subnets are summarized in a single subnet.

## Advantages of Supernetting

Supernetting provides the following advantages.

- It reduces the size of routing updates.
- It provides a better overview of the network.
- It decreases the use of resources such as Memory and CPU.
- It decreases the required time in rebuilding the routing tables.

## Example

Summarize these IP addresses into one network: (A summarized route)
• 192.168.0.0/24
• 192.168.1.0/24
• 192.168.2.0/24
• 192.168.3.0/24

*Step 1: Write all the IP Addresses in binary like so:*

192.168.0.0/24
11000000.10101000.00000000.00000000

192.168.1.0/24
11000000.10101000.00000001.00000000

192.168.2.0/24
11000000.10101000.00000010.00000000

192.168.3.0/24
11000000.10101000.00000011.00000000

*Step 2: Find matching bits from left to right*

11000000.10101000.00000000.00000000
11000000.10101000.00000001.00000000
11000000.10101000.00000010.00000000
11000000.10101000.00000011.00000000

- To avoid possible confusion, start by matching bits starting from the last IP address, then work your way up.

*Step 3: Re-write the matching numbers and add zeros for the non-matching bits; because you are converting network bits into host bits, each "newly acquired" host bit will be represented with a 0. Remember, network bits are represented with 1, host bits are represented with 0.*

This new network address will be your NEW NETWORK ID, the route that you will be advertising. (A summarized route)
11000000.10101000.00000000.00000000 = 192.168.0.0

*Step 4: Find the new subnet mask. Put "1s" in the matching networking part, and all zeros in the host part.*

11111111.11111111.11111100.00000000
This your new subnet mask 255.255.252.0
Your new summarized route is 192.168.0.0/22

## Wildcard Masks

Wildcard Masks are utilized in ACLs, to allow or deny traffic to a particular network; and routing protocols, to advertise certain routes in the routing table. In terms of the syntax, Wildcard masks are essentially the inverse of subnet masks:

- **Wildcard mask bit 0:** Match the corresponding bit value in the address. [Network Bit]
- **Wildcard mask bit 1:** Ignore the corresponding bit value in the address.[Host Bit]

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To determine the wildcard mask of a subnet,  you need to subtract 255.255.255.255 from the subnet mask:
e.g 255.255.255.0

    255.255.255.255
– 255.255.255.0
—-------------------------------------
0.0.0.255 is the Wildcard Mask

### Shortcut

With that being said, simply inverse the values of each octet in the subnet mask to find the wildcard mask:
e.g 255.255.255.0 = 0.0.0.255

## Wildcard Masks with Borrowed Bits

The same process applies to networks with borrowed bits:  you need to subtract the decimal value of the subnet mask from 255.255.255.255:
e.g 255.255.224.0

    255.255.255.255
– 255.255.224.0
—-----------------------------------
0.0.31.255 is the Wildcard Mask

### Shortcut

Simply inverse the non-mixed octets of the subnet mask and only subtract the decimal value of the mixed octet from .255:
255.255.224.0
Non-mixed Octets: 0.0.?.255

Decimal value of Mixed Octet: .224
    .255
- .224
—-------------
    .31

Full Wildcard Mask = 0.0.31.255

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*172.17.215.6 255.255.240.0*

Internal = 16
Mixed Octet = .215
Ranges = 172.17.208.0
172.17.224.0