802.11ac Wave 2 Technology Deep Dive and Deployment Recommendations

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Agenda

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- 11ac Standards Physical Layer Overview
- 11ac Data Rates
- Antennas
- 11ac Beamforming
- Field Results

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What is Wave 2?

802.11ac Technology Overview

Think of 11ac as an extension of 11n

- 11n specification introduced/leveraged:
  - 2.4 and 5 GHz supported
  - Wider channels (40 MHz)
  - Better modulation (64-QAM)
  - Additional streams (up to 4 streams)
  - Beam forming (explicit and implicit)
  - Backwards compatibility with 11a/b/g

11ac Wave 1 introduced:

- Even wider channels (80 MHz)
- Better modulation (256-QAM)
- Additional streams (up to 8)
- Beam forming (explicit)
- Backwards compatibility with 11a/b/g/n
  - Refer to http://www.802-11.ac.net for in-depth information

Wave 2 of 11ac

- **What will wave 2 802.11ac offer?**
  - MU-MIMO
    - Use AP MIMO resources more effectively
    - Transmit data to multiple devices simultaneously: for example 4SS AP streaming data to four 1SS clients simultaneously
  - 4x4:4SS
    - Benefit of additional stream mostly for MU-MIMO
    - Not anticipating any 4x4:4SS client devices
    - Adds 33% to max data rate in SU-MIMO
  - VHT160
    - Doubles max datarate
    - Practical problem: only 2 VHT160 channels available in entire 5GHz band
- **Max 5GHz radio data rates increases again!**
  - 450 (11n 3x3 HT40), 1,300 (11ac 3x3 VHT80), 3,467 (11ac 4x4 VHT160)
- **When will it be available?**
  - Products mid to late 2015
  - WFA certification scheduled for 2016

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Channel Allocations

Current 5GHz FCC Channel plan

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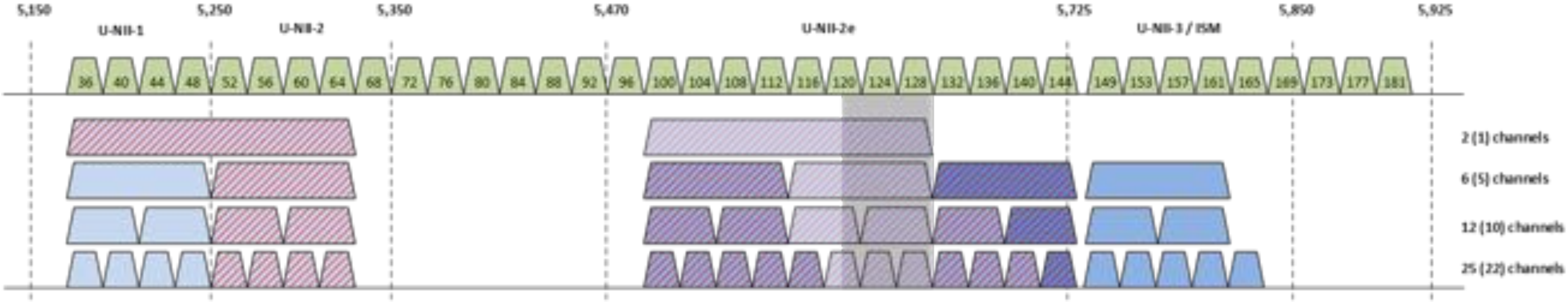

23dBm **30dBm** **30dBm** **36dBm**

Potential Future 5GHz FCC Channel plan

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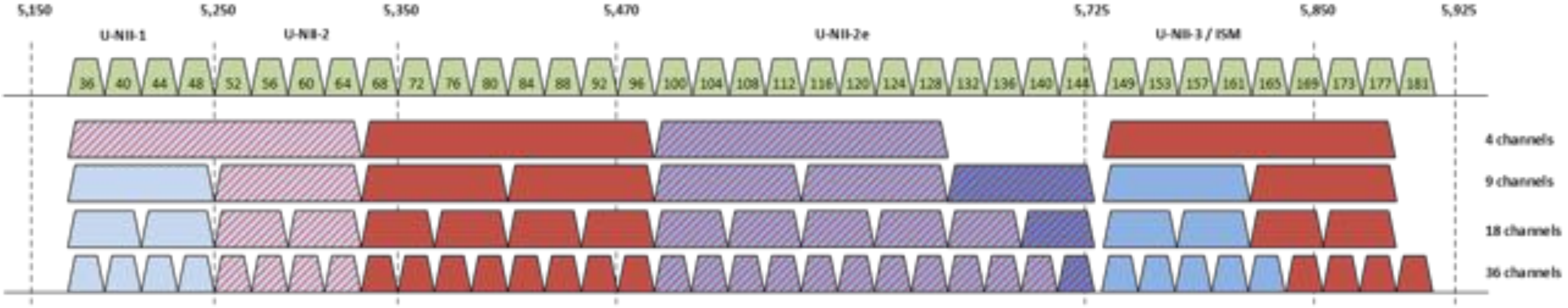
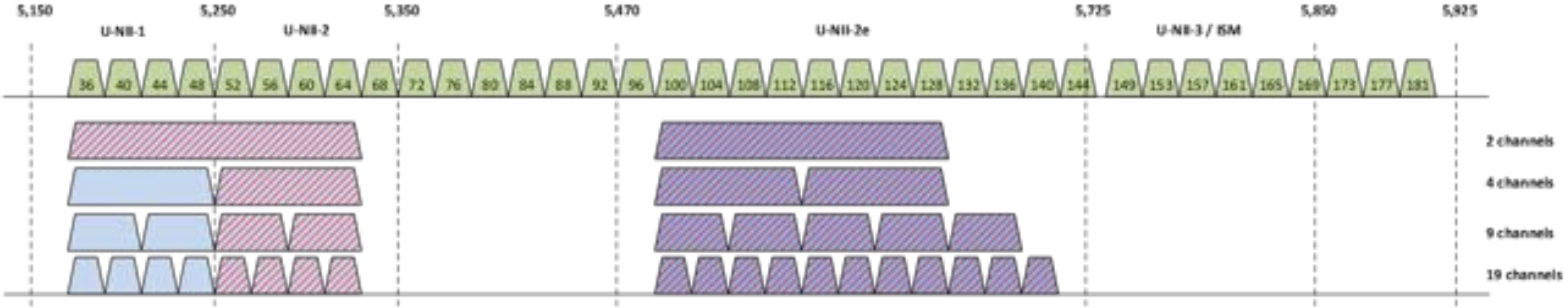


23dBm 30dBm TBD 30dBm 36dBm 30dBm

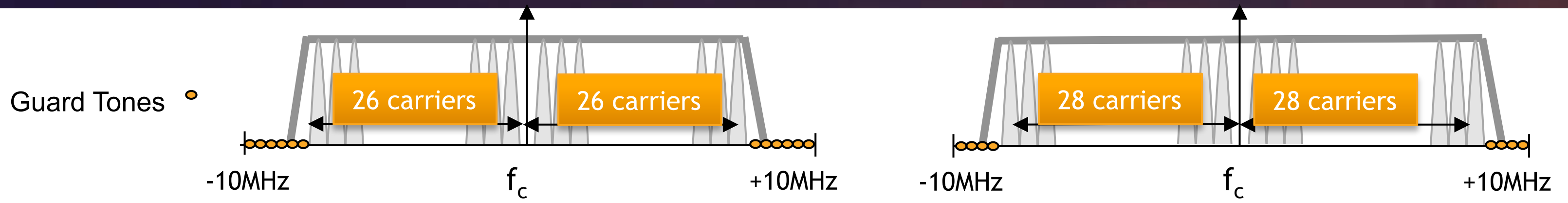
Current 5GHz ETSI Channel plan



23dBm 30dBm 30dBm

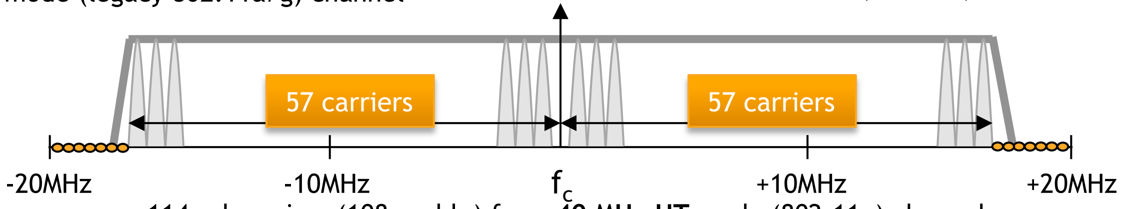
Understanding 11ac Data Rates (Wave 1 and Wave 2)

Sub-carriers

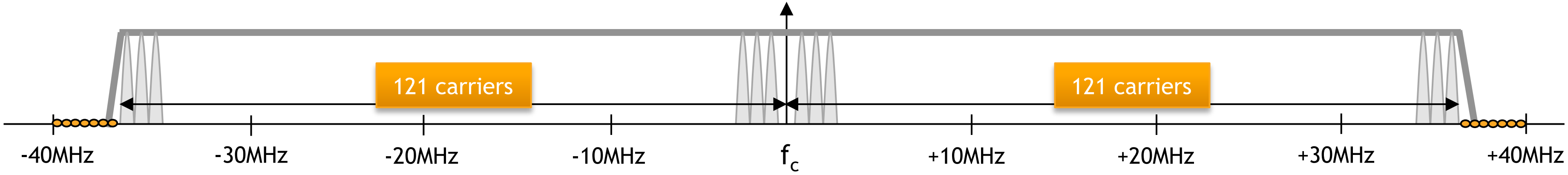


52 subcarriers (48 usable) for a **20 MHz non-HT** mode (legacy 802.11a/g) channel

56 subcarriers (52 usable) for a **20 MHz HT** mode (802.11n) channel



114 subcarriers (108 usable) for a **40 MHz HT** mode (802.11n) channel



242 subcarriers (234 usable) for a **80 MHz VHT** mode (802.11ac) channel

An 80+80MHz or 16MHz channel is exactly two 80MHz channels, for 484 subcarriers (468 usable)

OFDM subcarriers used in 802.11a, 802.11n and 802.11ac

Terminology

Symbol: basic element containing 1 to 8 bits of information

Tone/Sub-Carriers: OFDM is made up of many tones. Each symbol is mapped to a tone.

Cyclic Extension: technique used in OFDM to protect against multipath interference

- You need cyclic extension but it is dead air and consumes transmit time

Guard Band: Space between channels. In these regions tones have a constant value of zero amplitude

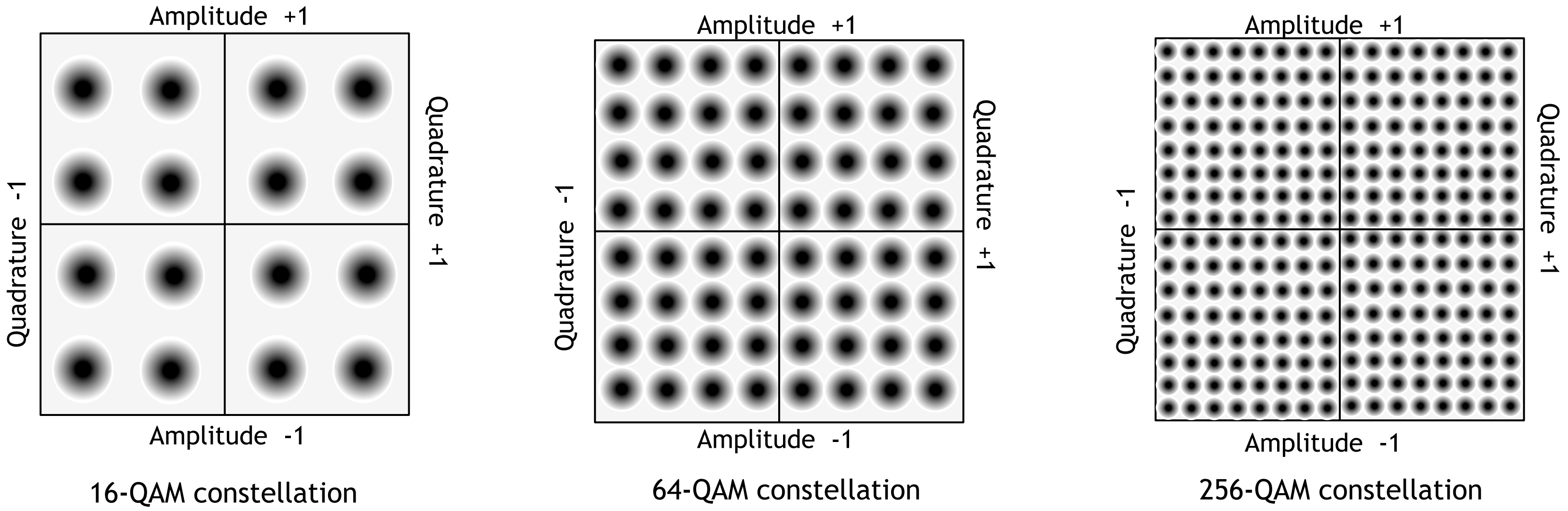
Pilot Tones: Used to train the receiver and estimate the channel

Radio Channel: For Wi-Fi 20, 40, 80, or 160 MHz of spectrum

Propagation Channel: everything that happens between the transmitter and receiver

FEC: Forward Error Correction. Redundant information that is sent to assist the receiver in decoding the bits.

QAM constellations



Constellation diagrams for 16-, 64-, 256-QAM

How do I get to the data rate for a given MCS?

Basic Symbol Rate
- 312.5 KHz
- 3.2 μs

Cyclic Extension
- t/4 0.8 μs (Long Guard Interval)
- t/8 0.4 μs (Short Guard Interval)

Bits Per Tone

– BPSK	1
– QPSK	2
– 16 QAM	4
– 64 QAM	6
– 256 QAM	8

Raw Data Rates

#Tones * Bits per Tone * Symbol Rate

- 16 QAM, 20 MHz
- 52 * 4 * 0.3125 = 65 Mbps

20 MHz		
BPSK	16.25	Mbps
QPSK	32.5	Mbps
16 QAM	65	Mbps
64 QAM	97.5	Mbps
256 QAM	130	Mbps

40 MHz		
BPSK	33.75	Mbps
QPSK	67.5	Mbps
16 QAM	135	Mbps
64 QAM	202.5	Mbps
256 QAM	270	Mbps

80 MHz		
BPSK	73.125	Mbps
QPSK	146.25	Mbps
16 QAM	292.5	Mbps
64 QAM	438.75	Mbps
256 QAM	585	Mbps

160 MHz		
BPSK	146.25	Mbps
QPSK	292.5	Mbps
16 QAM	585	Mbps
64 QAM	877.5	Mbps
256 QAM	1170	Mbps

Correct for Cyclic Extension

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20 MHz	t/4	
BPSK	13	Mbps
QPSK	26	Mbps
16 QAM	52	Mbps
64 QAM	78	Mbps
256 QAM	104	Mbps

20 MHz	t/8	
BPSK	14.4	Mbps
QPSK	28.9	Mbps
16 QAM	57.8	Mbps
64 QAM	86.7	Mbps
256 QAM	115.6	Mbps

80 MHz	t/4	
BPSK	58.5	Mbps
QPSK	117	Mbps
16 QAM	234	Mbps
64 QAM	351	Mbps
256 QAM	468	Mbps

80 MHz	t/8	
BPSK	65	Mbps
QPSK	130	Mbps
16 QAM	260	Mbps
64 QAM	390	Mbps
256 QAM	520	Mbps

40 MHz	t/4	
BPSK	27	Mbps
QPSK	54	Mbps
16 QAM	108	Mbps
64 QAM	162	Mbps
256 QAM	216	Mbps

40 MHz	t/8	
BPSK	30	Mbps
QPSK	60	Mbps
16 QAM	120	Mbps
64 QAM	180	Mbps
256 QAM	240	Mbps

160 MHz	t/4	
BPSK	117	Mbps
QPSK	234	Mbps
16 QAM	468	Mbps
64 QAM	702	Mbps
256 QAM	936	Mbps

160 MHz	t/8	
BPSK	130	Mbps
QPSK	260	Mbps
16 QAM	520	Mbps
64 QAM	780	Mbps
256 QAM	1040	Mbps

Apply FEC Coding

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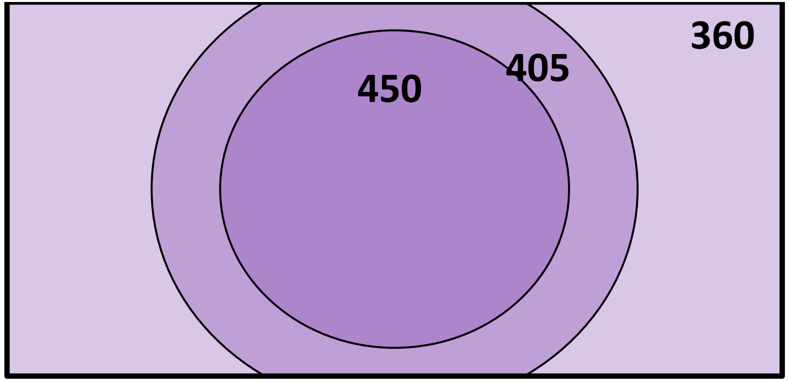
t/4			Net Bit Rate per Stream			
MCS Index	Modulation	Coding	20 MHz	40 MHz	80 MHz	160 MHz
0	BPSK	1/2	6.5	13.5	29.3	58.5
1	QPSK	1/2	13.0	27.0	58.5	117.0
2	QPSK	3/4	19.5	40.5	87.8	175.5
3	16 QAM	1/2	26.0	54.0	117.0	234.0
4	16 QAM	3/4	39.0	81.0	175.5	351.0
5	64 QAM	2/3	52.0	108.0	234.0	468.0
6	64 QAM	3/4	58.5	121.5	263.3	526.5
7	64 QAM	5/6	65.0	135.0	292.5	585.0
8	256 QAM	3/4	78.0	162.0	351.0	702.0
9	256 QAM	5/6	86.7	180.0	390.0	780.0

t/8 SGI			Net Bit Rate			
MCS Index	Modulation	Coding	20 MHz	40 MHz	80 MHz	160 MHz
0	BPSK	1/2	7.2	15.0	32.5	65.0
1	QPSK	1/2	14.4	30.0	65.0	130.0
2	QPSK	3/4	21.7	45.0	97.5	195.0
3	16 QAM	1/2	28.9	60.0	130.0	260.0
4	16 QAM	3/4	43.3	90.0	195.0	390.0
5	64 QAM	2/3	57.8	120.0	260.0	520.0
6	64 QAM	3/4	65.0	135.0	292.5	585.0
7	64 QAM	5/6	72.2	150.0	325.0	650.0
8	256 QAM	3/4	86.7	180.0	390.0	780.0
9	256 QAM	5/6	96.3	200.0	433.3	866.7

Practical Coverage

Coverage Example

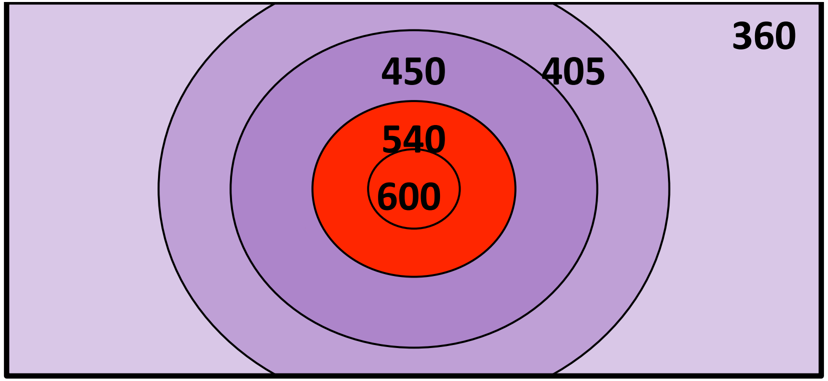
1. Sample coverage for 3x3:3 11n AP (or 3x3:3 11ac AP with 11n clients) in HT40 mode



- Coverage area sustains MCS5 and up

Coverage Example

2. Upgrade to 3x3:3 11ac AP with 11ac clients, still using 40Mhz channels (VHT40)



Radius for 600Mbps (MCS9) area is 1/4 of that for 450Mbps (MCS7)

Coverage Example

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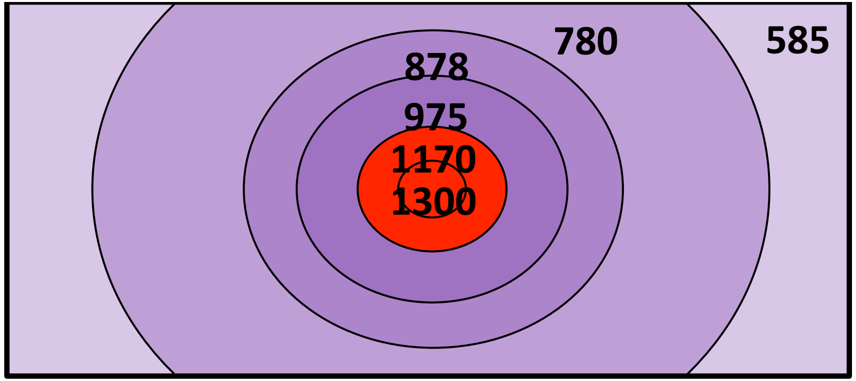
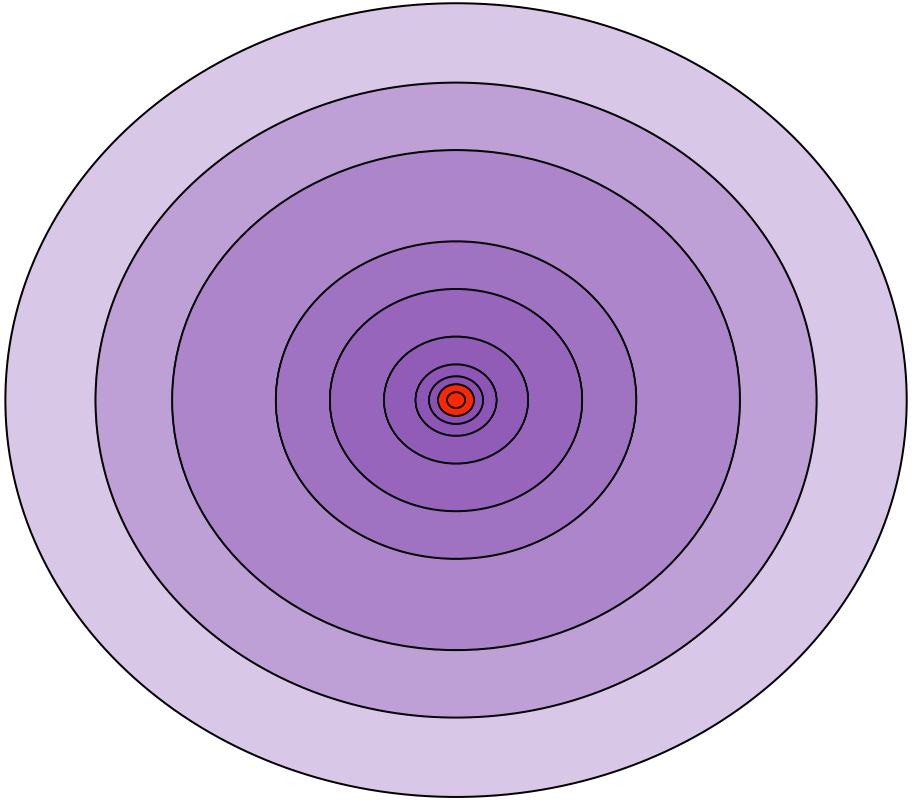
3. Equivalent range for clients using 80MHz channels (VHT80)



– Rates roughly double, relative range for each of the MCS rates does not change, but 80MHz range is ~70% of equivalent (same MCS) 40MHz range

Relative Range 802.11ac Rates



Signal level and relative range

	-dB	r %
MCS0	**87**	**63**
MCS1	**85**	**50**
MCS2	**83**	**40**
MCS3	**79**	**25**
MCS4	**76**	**18**
MCS5	**71**	**10**
MCS6	**66**	**5.6**
MCS7	**63**	**4.0**
MCS8	**58**	**2.2**
MCS9	**51**	**1.0**

Datarate

	40MHz	80MHz
MCS0	**45**	**97.5**
MCS1	**90**	**195**
MCS2	**135**	**292.5**
MCS3	**180**	**390**
MCS4	**270**	**585**
MCS5	**360**	**780**
MCS6	**405**	**877.5**
MCS7	**450**	**975**
MCS8	**540**	**1,170**
MCS9	**600**	**1,300**

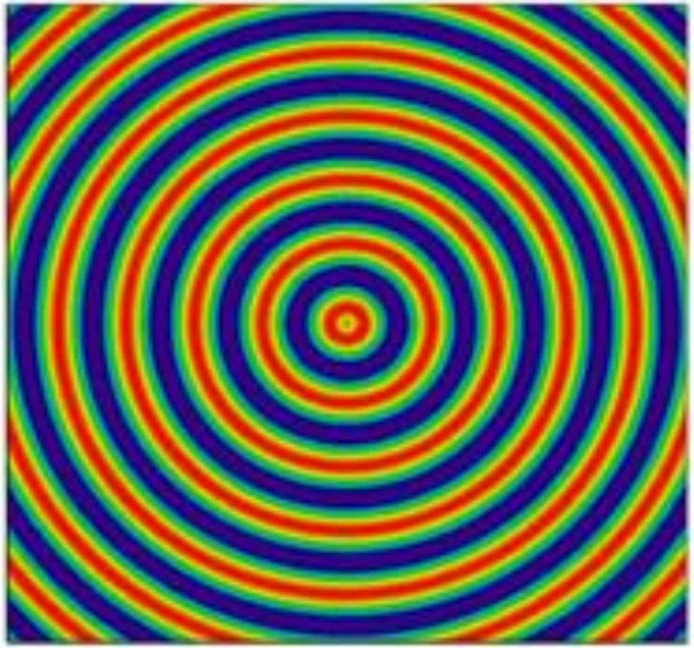
What about Wave 2 coverage?

- 160 MHz is just two 80 MHz sandwiched together
  - No increase in noise floor
- No new modulations are introduced
  - No new circles in the bullseye
- Additional streams do not change coverage area

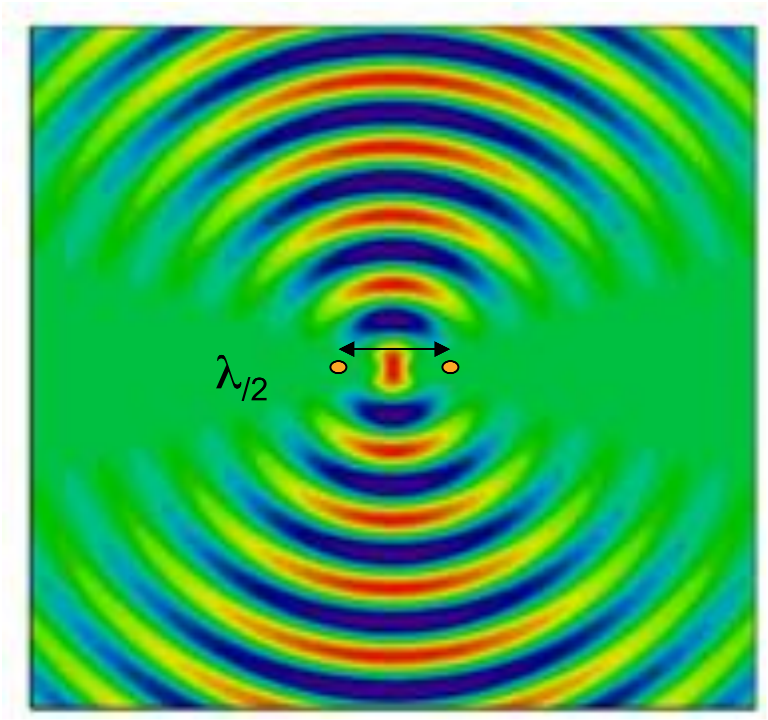
BASIC BEAMFORMING

Antenna Basic Physics

- When the charges oscillate the waves go up and down with the charges and radiate away
- With a single element the energy leaves uniformly.
- Also known as omni-directionally

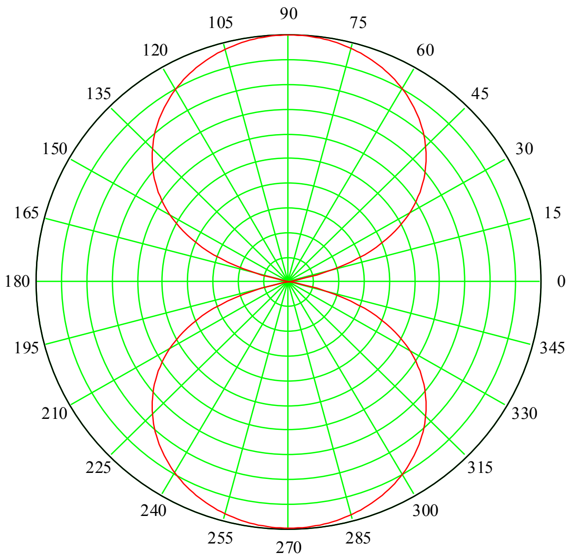


Building Arrays: 2 Elements

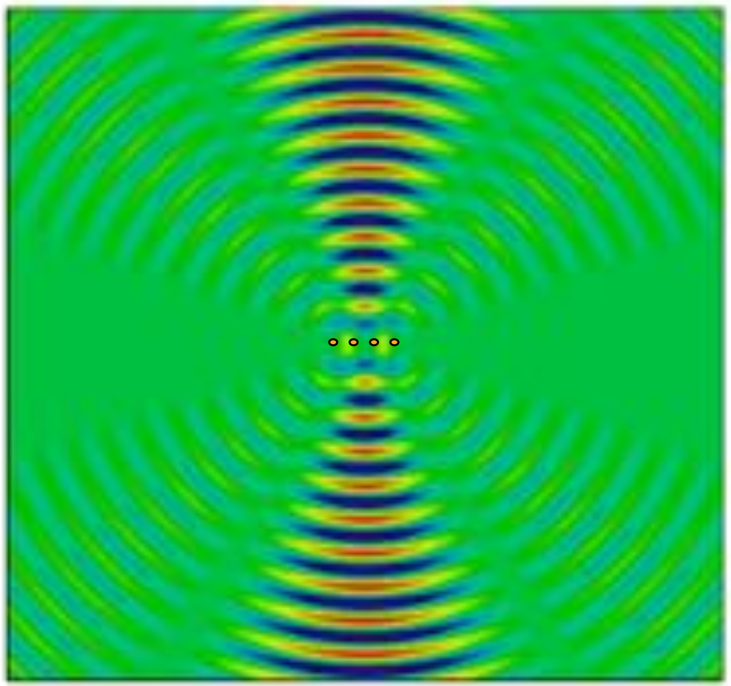


- **By introducing additional antenna elements we can control the way that the energy radiates**
- **2 elements excited in phase**

dB Plot

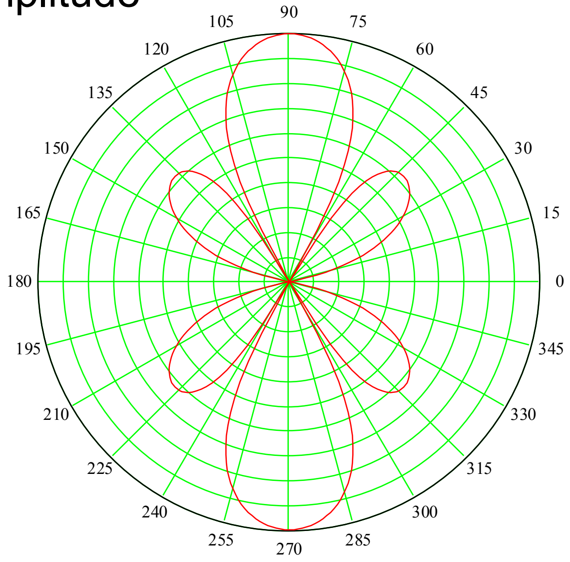


Building Arrays: 4 Elements

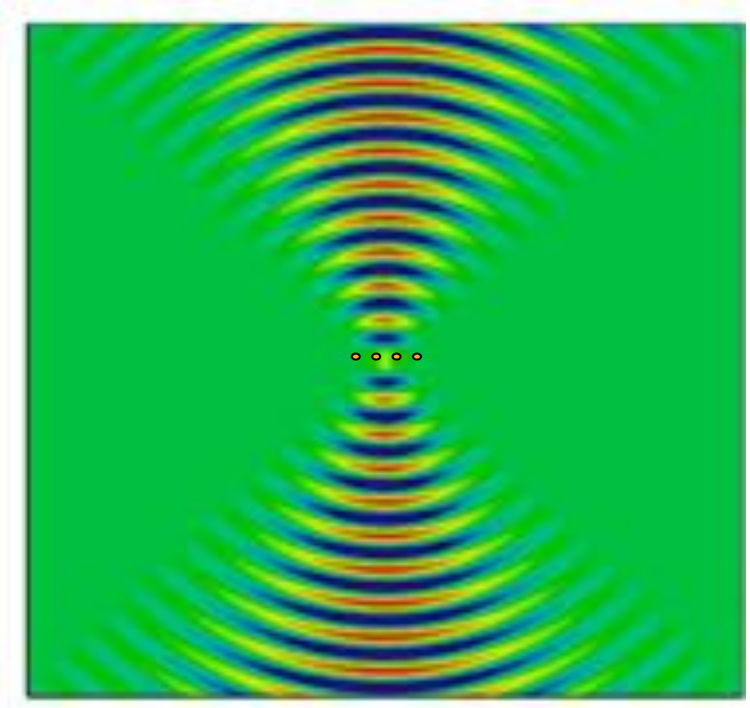


- **By introducing additional antenna elements we can control the way that the energy radiates**
- **4 elements excited in phase**
  - Equal amplitude

dB Plot

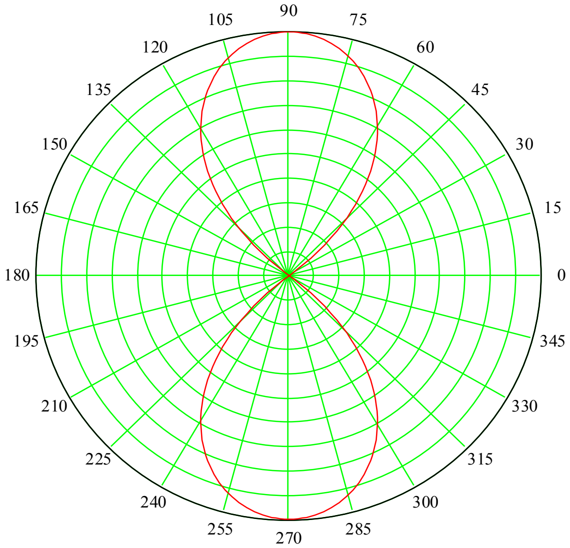


Building Arrays: 4 Elements

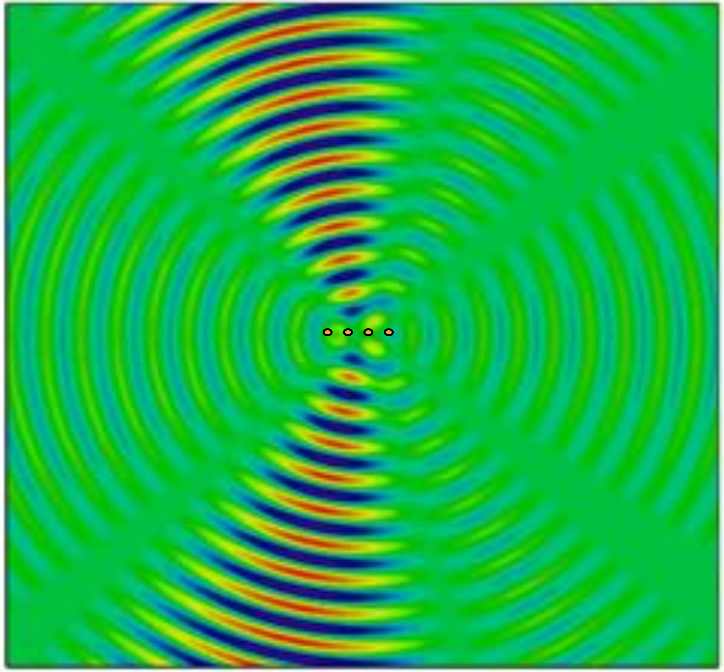


- By shaping the amplitude we can control sidelobes
- 4 elements excited in phase
  - Amplitude 1, 3, 3, 1

dB Plot

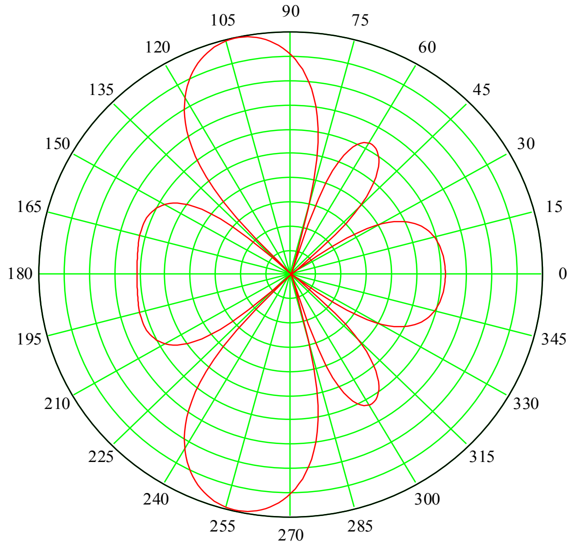


Building Arrays: 4 Elements Phase



- By altering phase we can alter the direction that the energy travels
- 4 elements excited with phase slope
  - Equal amplitude

dB Plot



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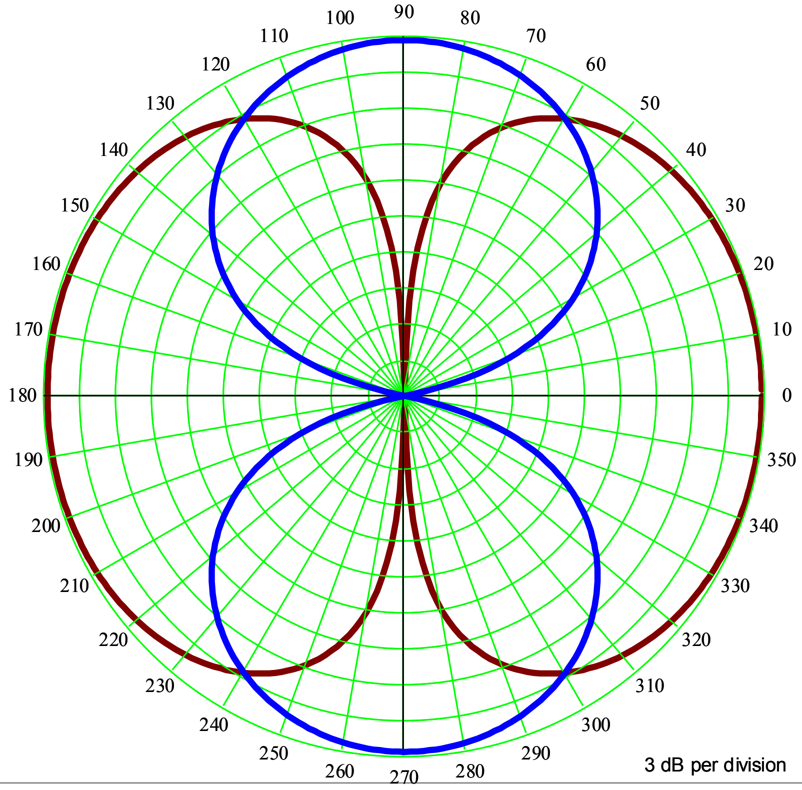
Orthogonal Patterns

2 Elements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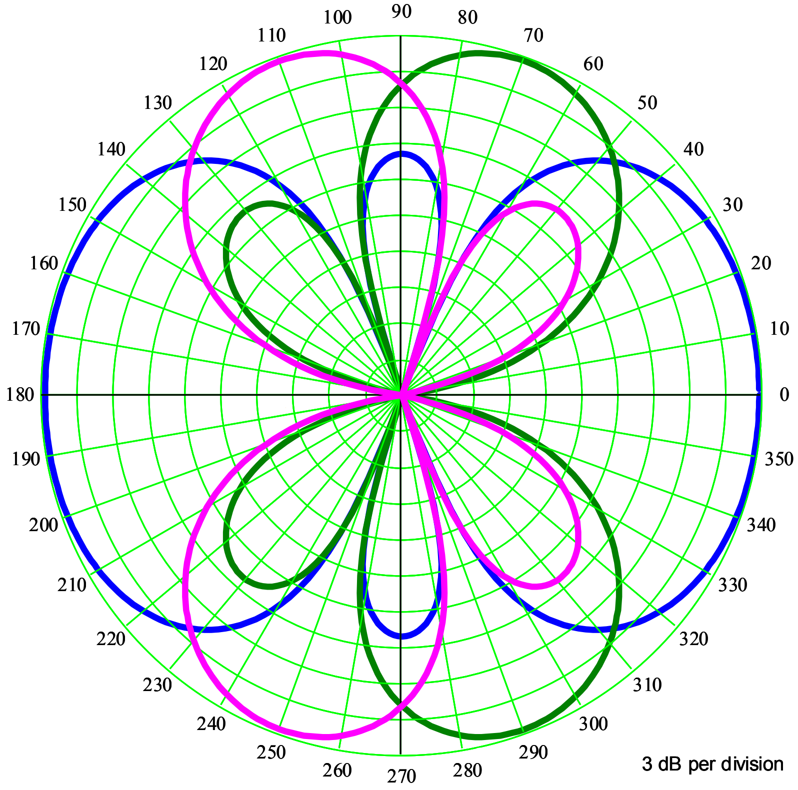
3 dB per division

3 Elements



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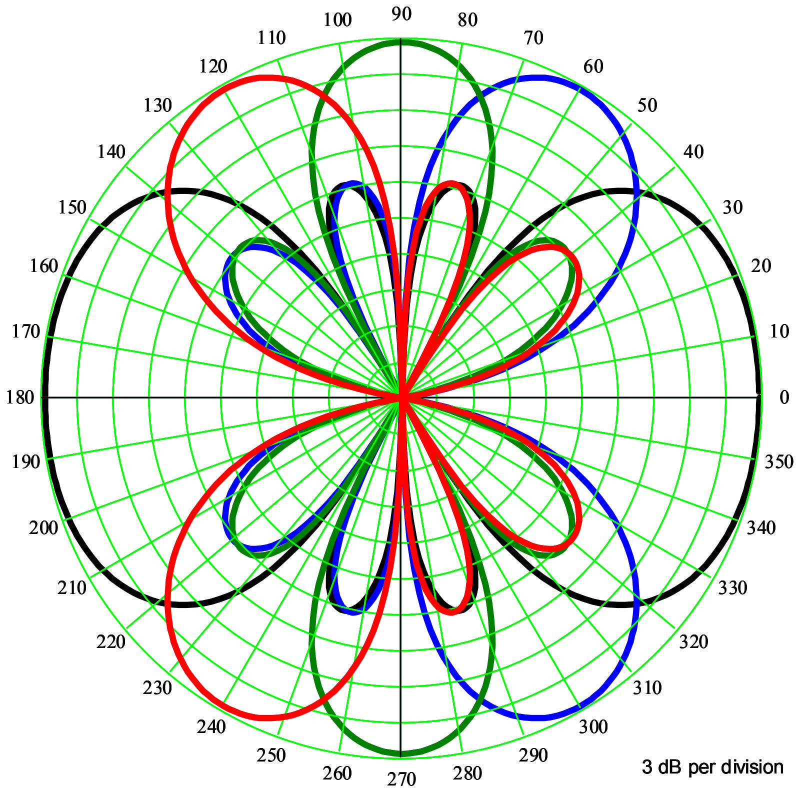
3 dB per division

4 Elements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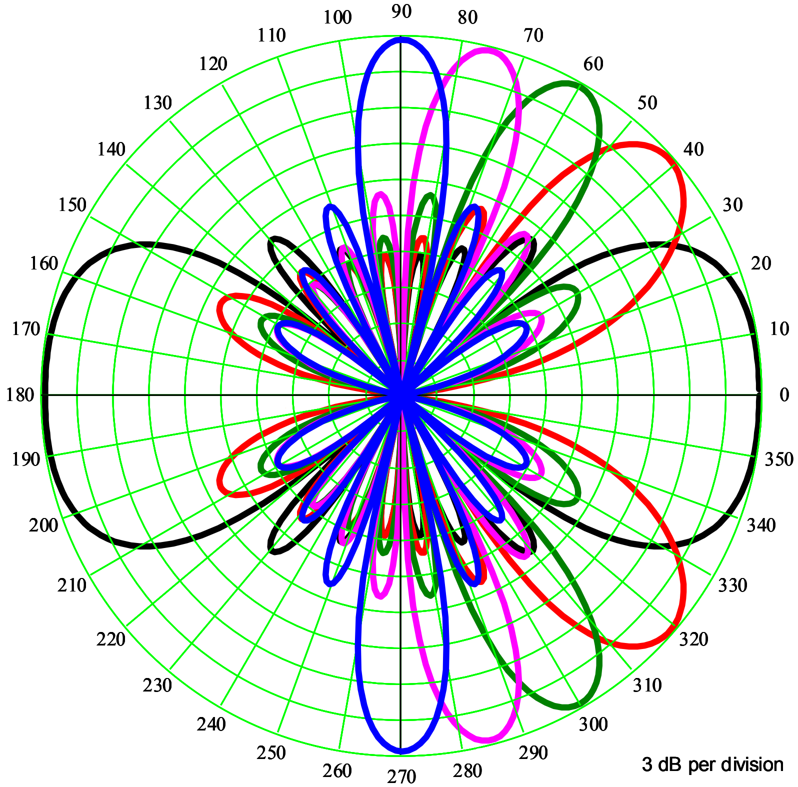
3 dB per division

8 Elements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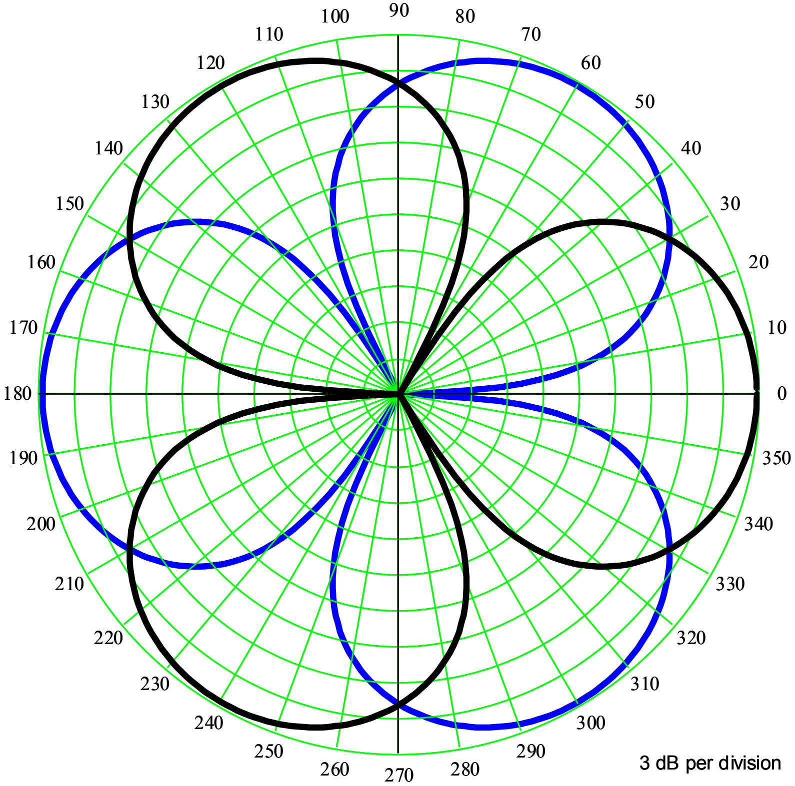
3 dB per division

Triangular 3 element



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802.11ac Beamforming

11ac Beamforming: Notes

Works with clients that support 11ac beamforming function
- This is at a minimum all 11ac client devices using Broadcom chipsets
- Support will have to come to all devices to compete with Broadcom offering

11ac beamforming is standards based
- first standard that is doing this the “right” way
- 11ac beamforming represents the consensus view of the 1000’s of contributors to the standards process

11ac beamforming is implemented in baseband.
- It works with all antenna subsystems
- The total number of beamforming combinations is effectively infinite

11ac actively tracks users so has a recent channel estimate between the AP and client that is updated frequently

Background

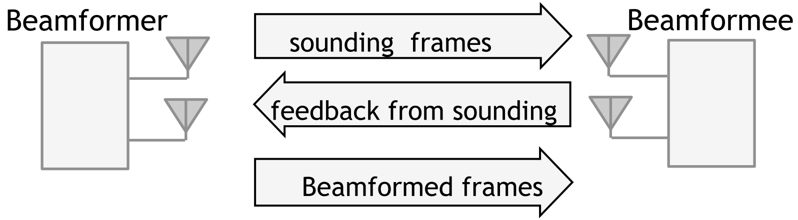
11n/11ac MIMO

- 1 Stream
  - All antenna elements send same data with time delay
- 3 Streams
  - 1 Stream is sent on each antenna

11ac Beamforming

- 1 Stream
  - Stream is spatially multiplexed across the three antennas
  - Same info but phase and amplitude differences
- 3 Streams
  - All three streams are spatially multiplexed across the three antennas

Sounding process

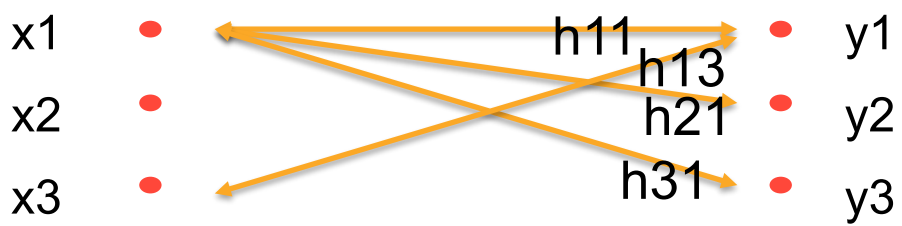


Explicit feedback for beamforming (802.11ac)
1 (Beamformer) Here's a sounding frame
2 (Beamformee) Here's how I heard the sounding frame
3 Now I will pre-code to match how you heard me

Explicit feedback for beamforming

The Basic Model: Regular MIMO

$$\begin{pmatrix} y1 \\ y2 \\ y3 \end{pmatrix} = \begin{pmatrix} h11 & h12 & h13 \\ h21 & h22 & h23 \\ h31 & h32 & h33 \end{pmatrix} \cdot \begin{pmatrix} x1 \\ x2 \\ x3 \end{pmatrix}$$

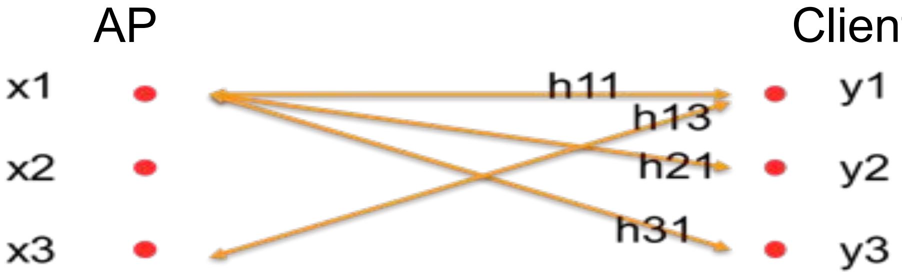


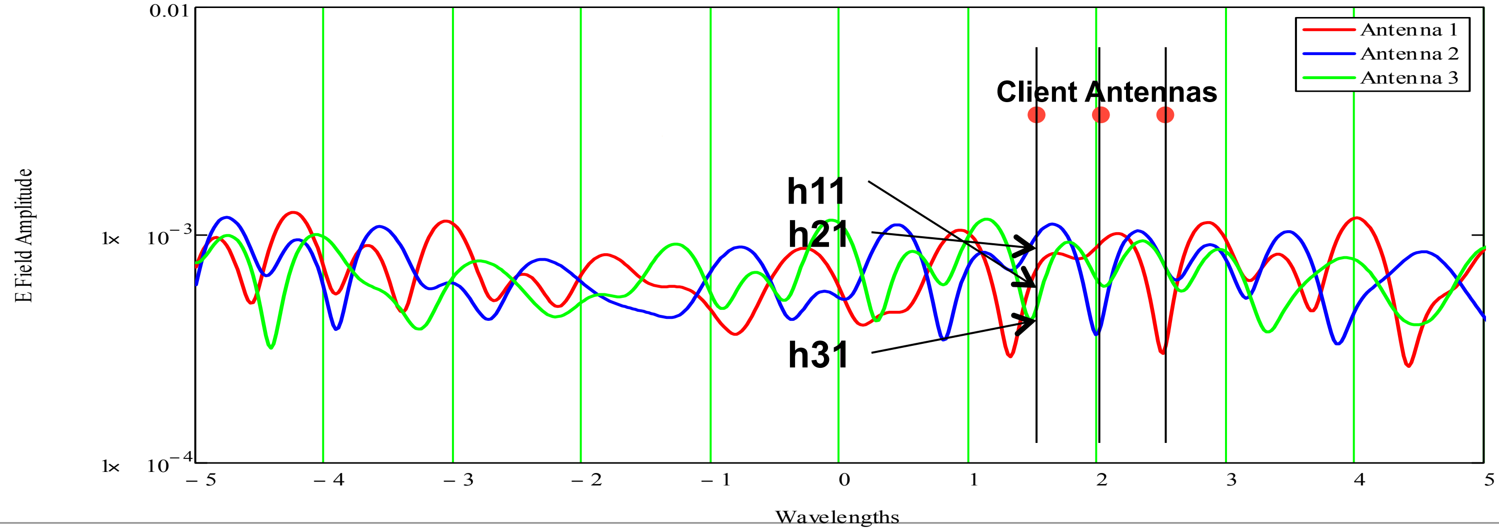
y=Hx

- H is the propagation channel
- y is what comes out of each antenna at the receiving end
- With 3 tx and 3 rx antennas H is a 3x3 matrix, y and x are single vectors
- If you can determine the inverse matrix of H you can calculate
  - Client receiver estimates this from preamble and pilot tones
- $H^{-1}y=H^{-1}Hx$
  - $H^{-1}y=x$

The MATRIX

$$\begin{pmatrix} y1 \\ y2 \\ y3 \end{pmatrix} = \begin{pmatrix} h11 & h12 & h13 \\ h21 & h22 & h23 \\ h31 & h32 & h33 \end{pmatrix} \cdot \begin{pmatrix} x1 \\ x2 \\ x3 \end{pmatrix}$$





Beamforming

- **If the client can send back the channel estimate to the AP then beamforming can be executed**
- **The signal from each antenna then is a combination of the three stream**

Beamformed Streams →

$$\begin{pmatrix} s1 \\ s2 \\ s3 \end{pmatrix} = \begin{pmatrix} h11 & h12 & h13 \\ h21 & h22 & h23 \\ h31 & h32 & h33 \end{pmatrix}^{-1} \cdot \begin{pmatrix} x1 \\ x2 \\ x3 \end{pmatrix}$$

← Non Beamformed Streams

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Practical Examples: Beamforming

Dual Polarization

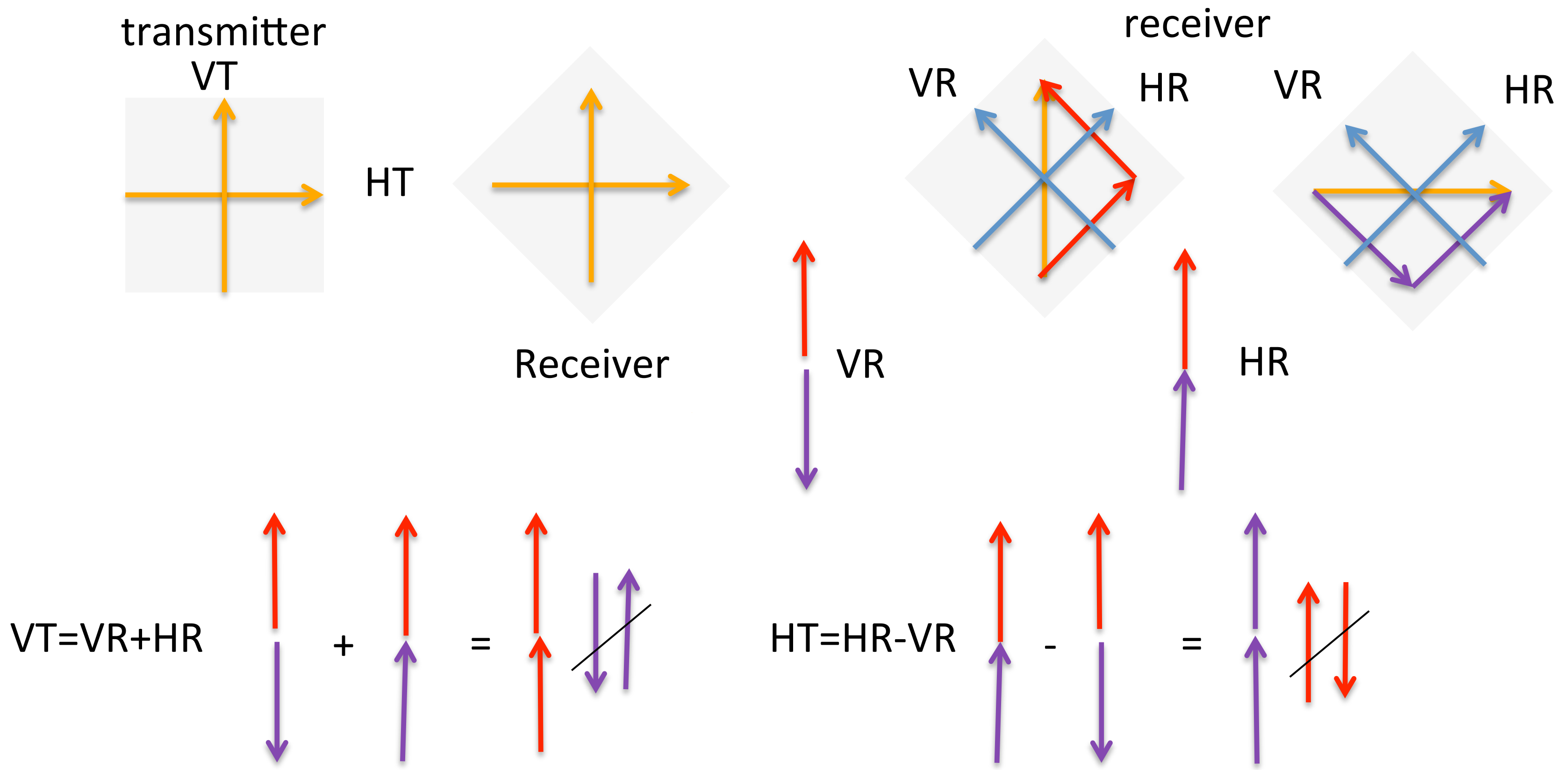
- **At the source end**
  - one signal is vertically polarized
  - other is horizontally polarized
- **At the receiver the antenna is oriented the same way.**
  - With a line of sight link the V signal ends up on the V port
  - The H signal shows up on the H port
- **In propagation terms this is simply**

$$\begin{pmatrix} VR \\ HR \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \cdot \begin{pmatrix} VT \\ HT \end{pmatrix}$$

- **What if the receiver is rotated by 45 degrees. The H and V pol divide onto to the two rotated port on the receiver**

$$\begin{pmatrix} VR \\ HR \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \end{pmatrix} \cdot \begin{pmatrix} VT \\ HT \end{pmatrix}$$

MIMO in Action: Polarization

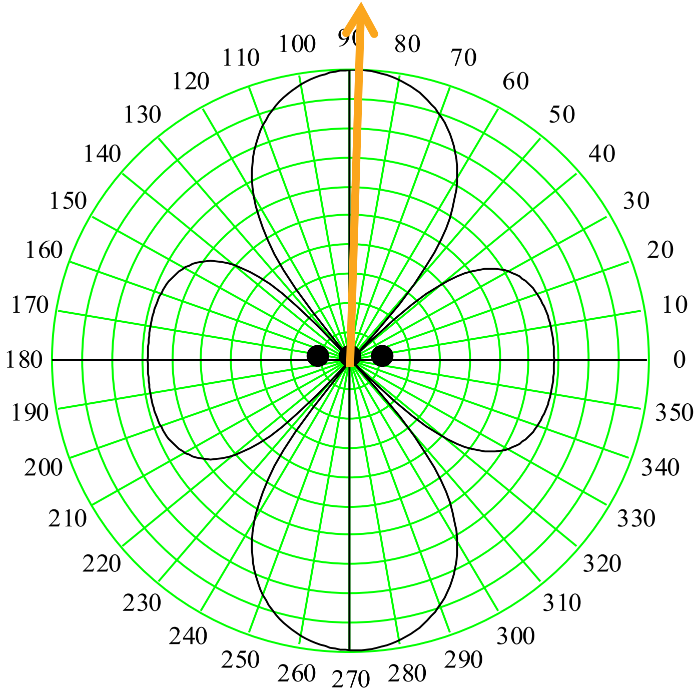


Line of Sight

- **3 stream AP**
- **Smartphone**
  - 1 Antenna/1 Stream

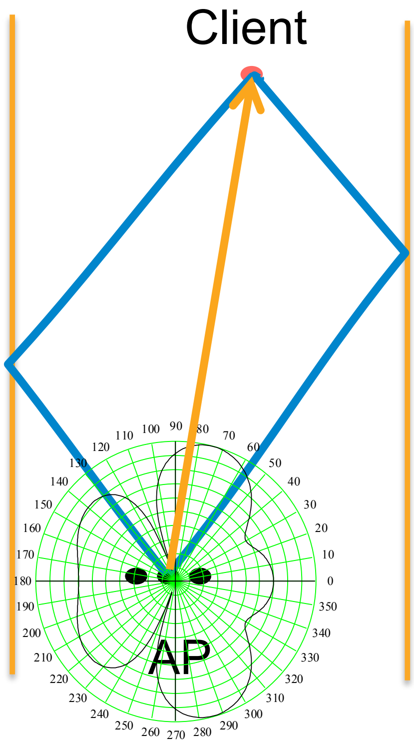
Client

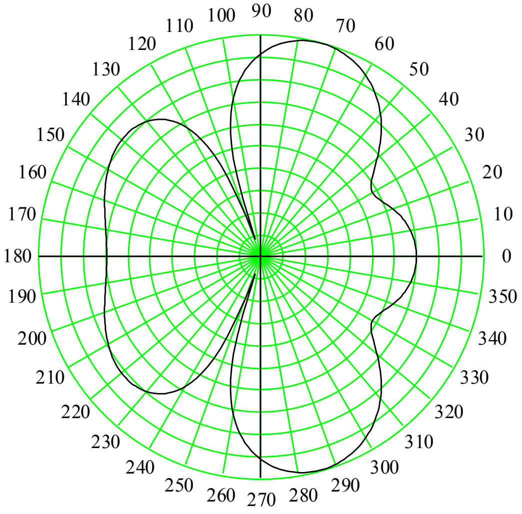
AP



Simple Reflection

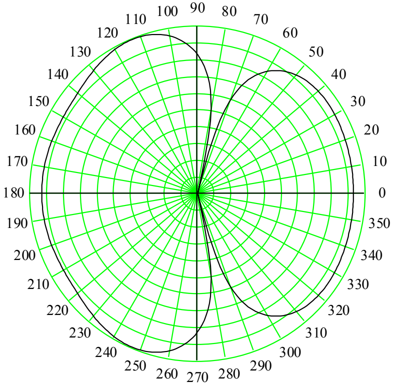
- **Let's introduce two reflection surfaces and look at the impact of one bounce on each side**



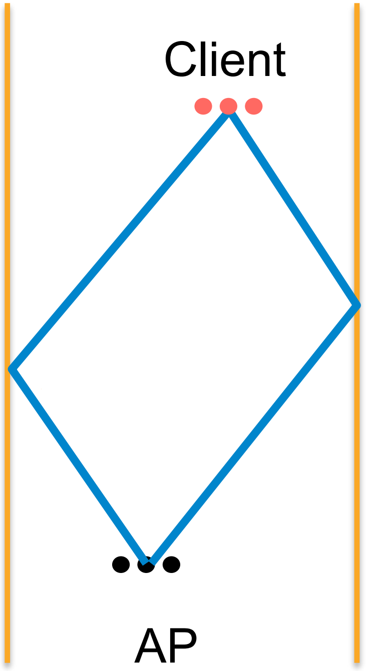


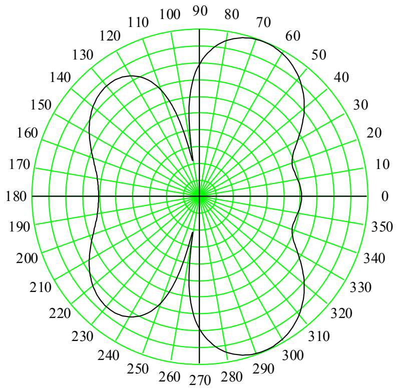
Multi Stream Client

- **The reflections allow beamforming to send different streams with different antenna patterns through the system**

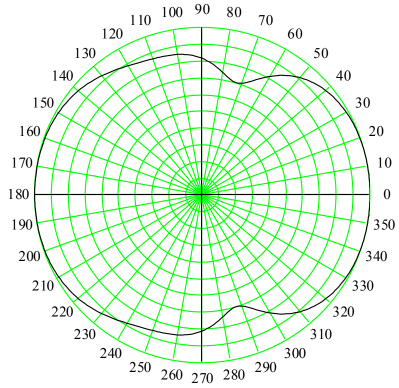


Stream 1





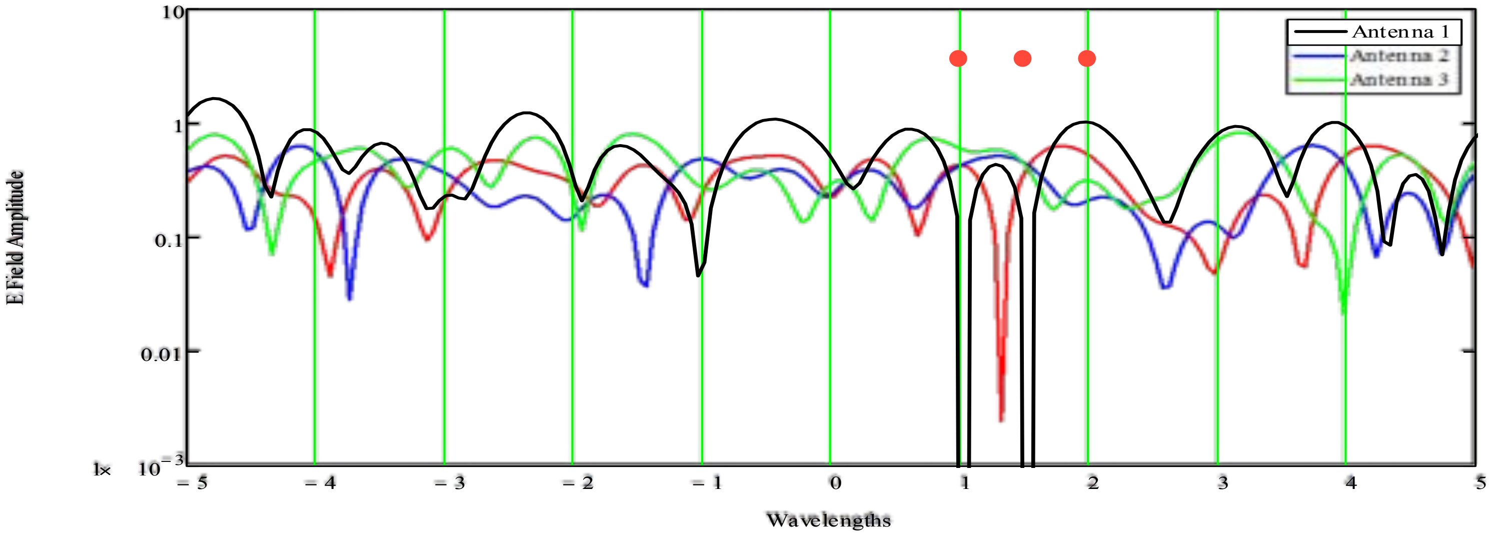
Stream 2



Stream 3

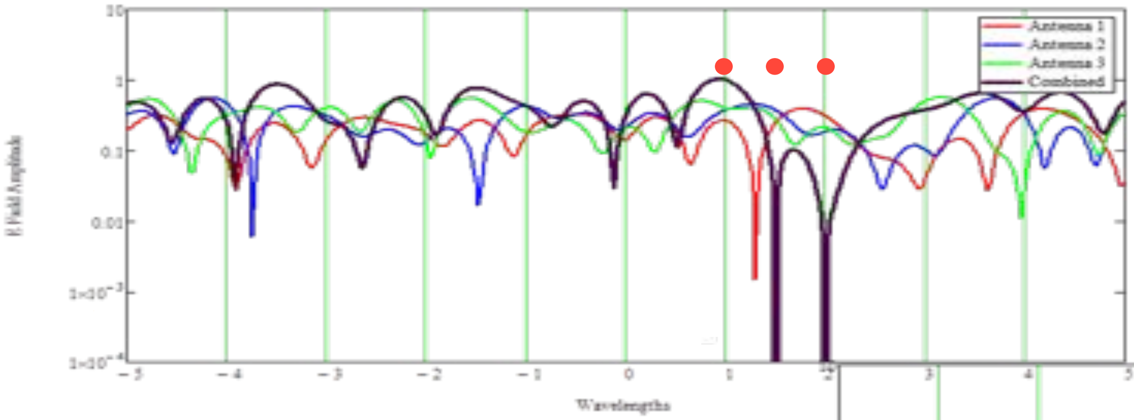
Stream 3 now appears on all three antenna

– **Here is how each transmitted component shows up at the client**

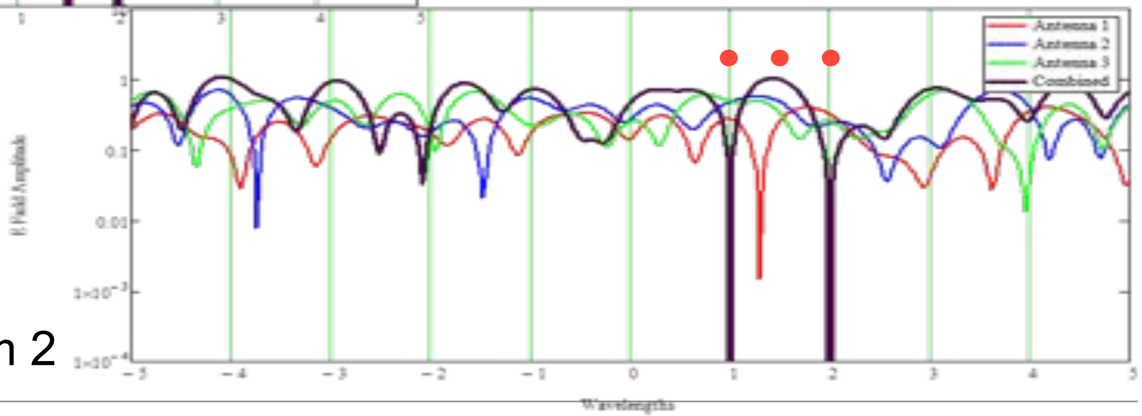


Now add them!

Similarly Stream 1 and 2

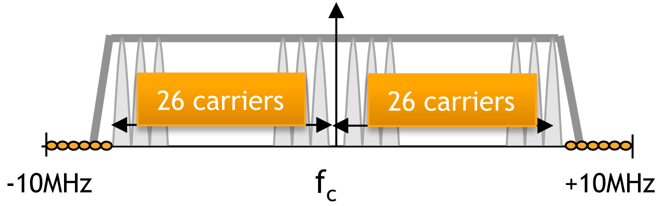


Stream 1

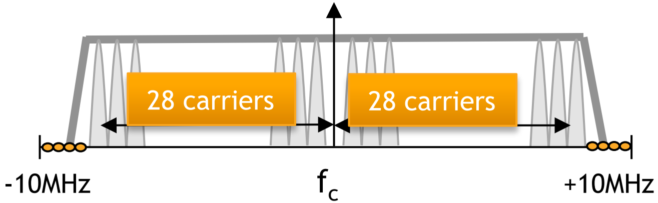


Stream 2

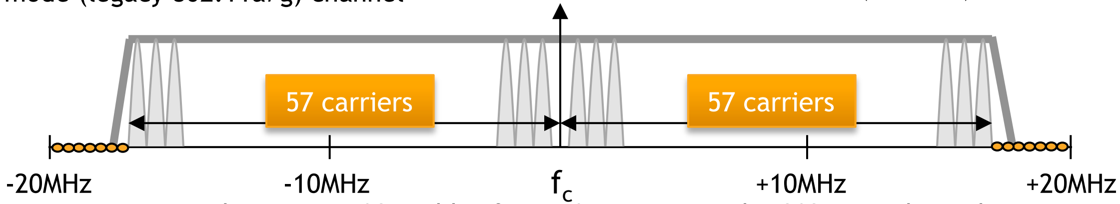
Guard Tones



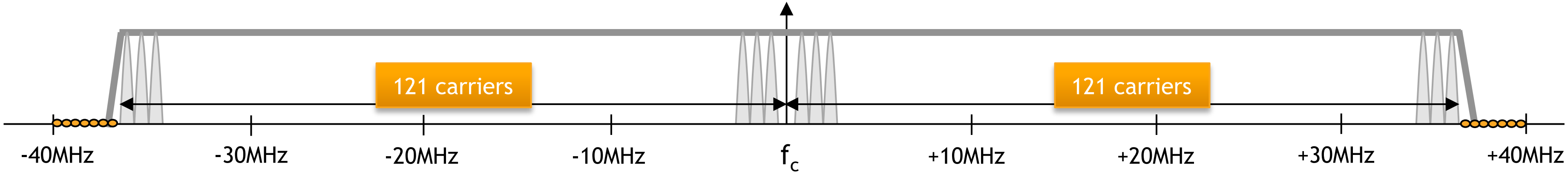
52 subcarriers (48 usable) for a **20 MHz non-HT** mode (legacy 802.11a/g) channel



56 subcarriers (52 usable) for a **20 MHz HT** mode (802.11n) channel



114 subcarriers (108 usable) for a **40 MHz HT** mode (802.11n) channel

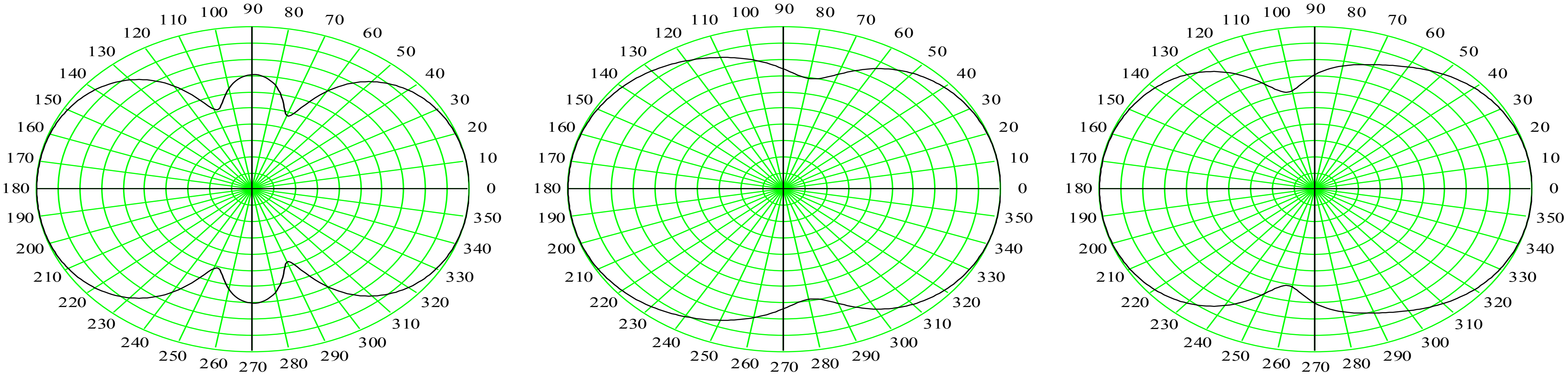


242 subcarriers (234 usable) for a **80 MHz VHT** mode (802.11ac) channel
An 80+80MHz or 16MHz channel is exactly two 80MHz channels, for 484 subcarriers (468 usable)

<u>OFDM subcarriers used in 802.11a, 802.11n and 802.11ac</u>

The standards based algorithm actually works out patterns for each sub carrier

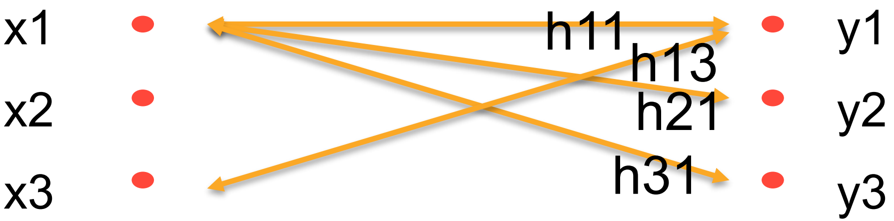
Below is the pattern for stream 1 at 5460, 5500, 5540 MHz



802.11ac MU-MIMO

The Basic Model: MU-MIMO

$$\begin{pmatrix} y1 \\ y2 \\ y3 \end{pmatrix} = \begin{pmatrix} h11 & h12 & h13 \\ h21 & h22 & h23 \\ h31 & h32 & h33 \end{pmatrix} \begin{pmatrix} x1 \\ x2 \\ x3 \end{pmatrix}$$



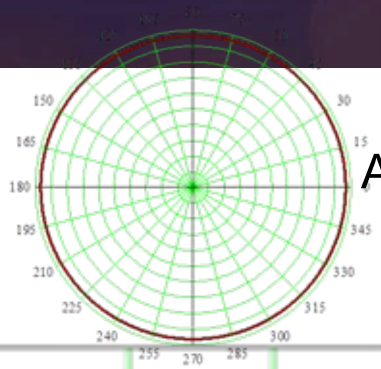
With MU-MIMO each client sends a piece of the matrix

y=Hx

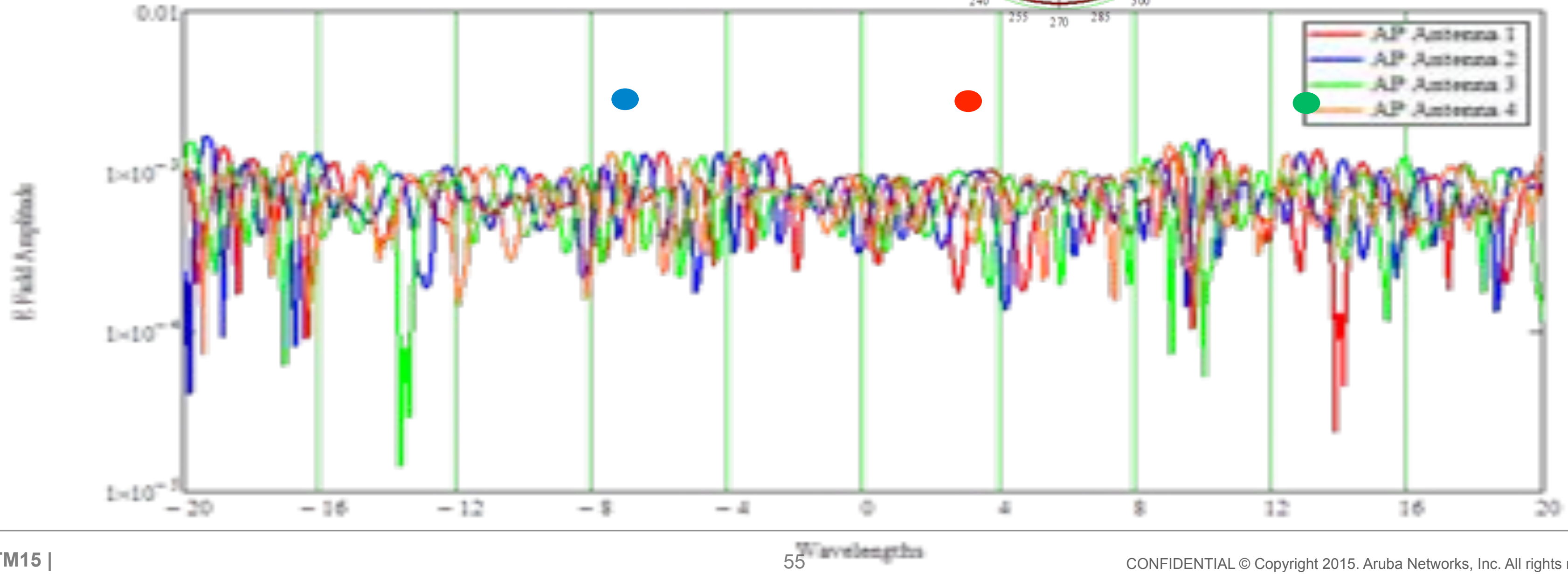
- H is the propagation channel
- y is what comes out of each antenna at each of the clients
- The channel matrix is built from sounding each client

3 Clients: 4x4 AP

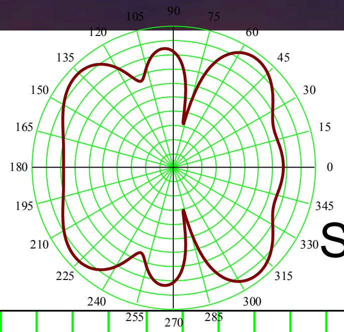
Room Width: 10m
Room Length: 10m
Room Height: 7m



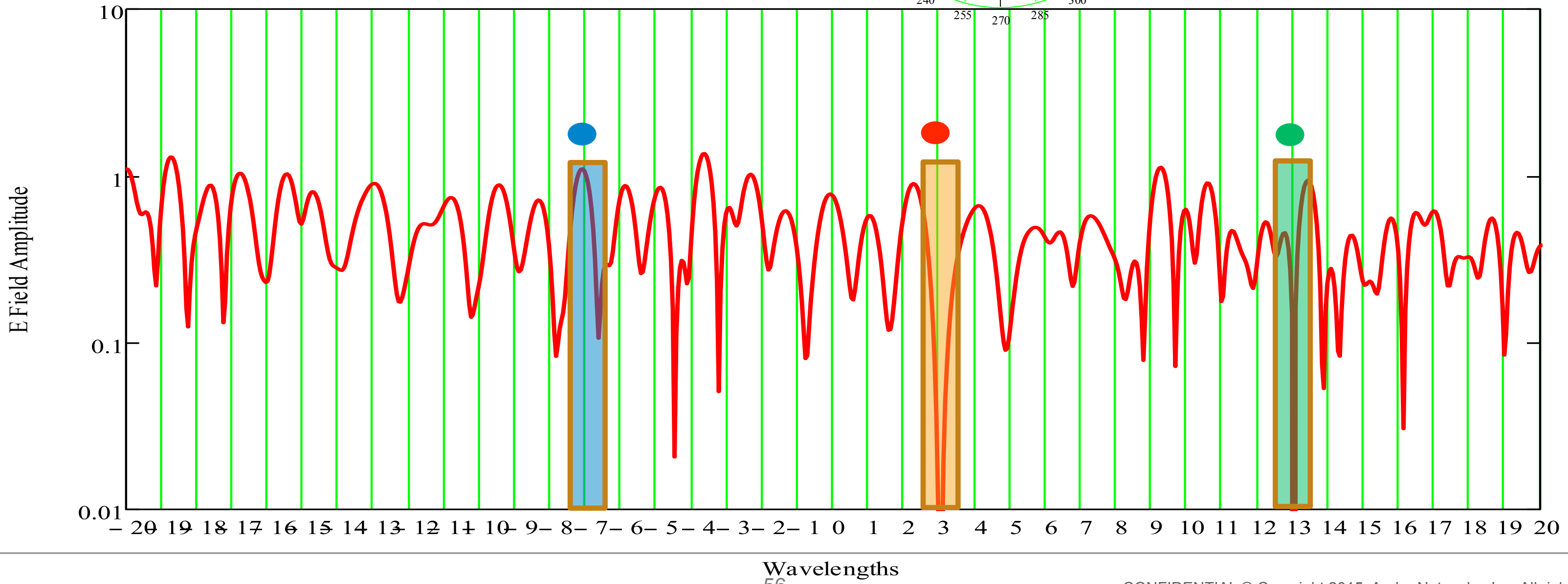
AP Antenna Pattern



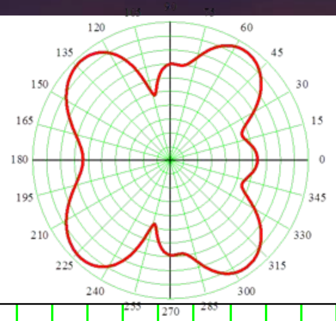
Stream 1 to Client 1



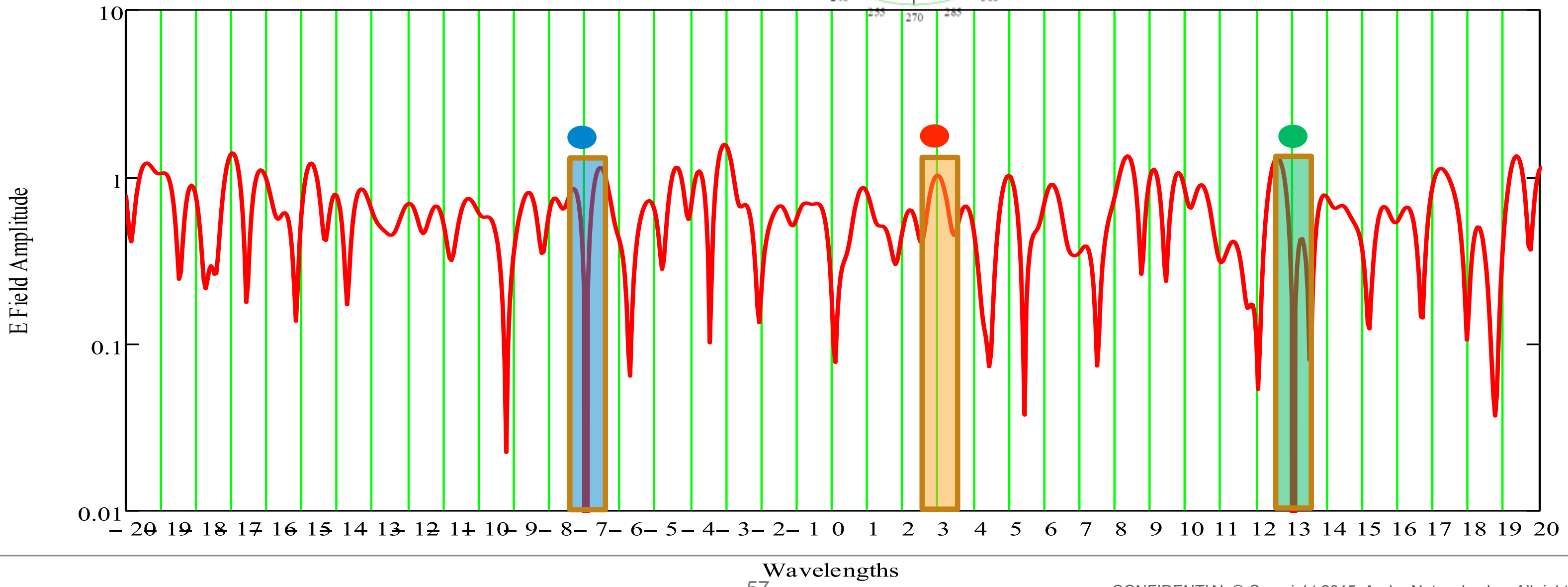
Stream 1 Antenna Pattern



Stream 2 to Client 2

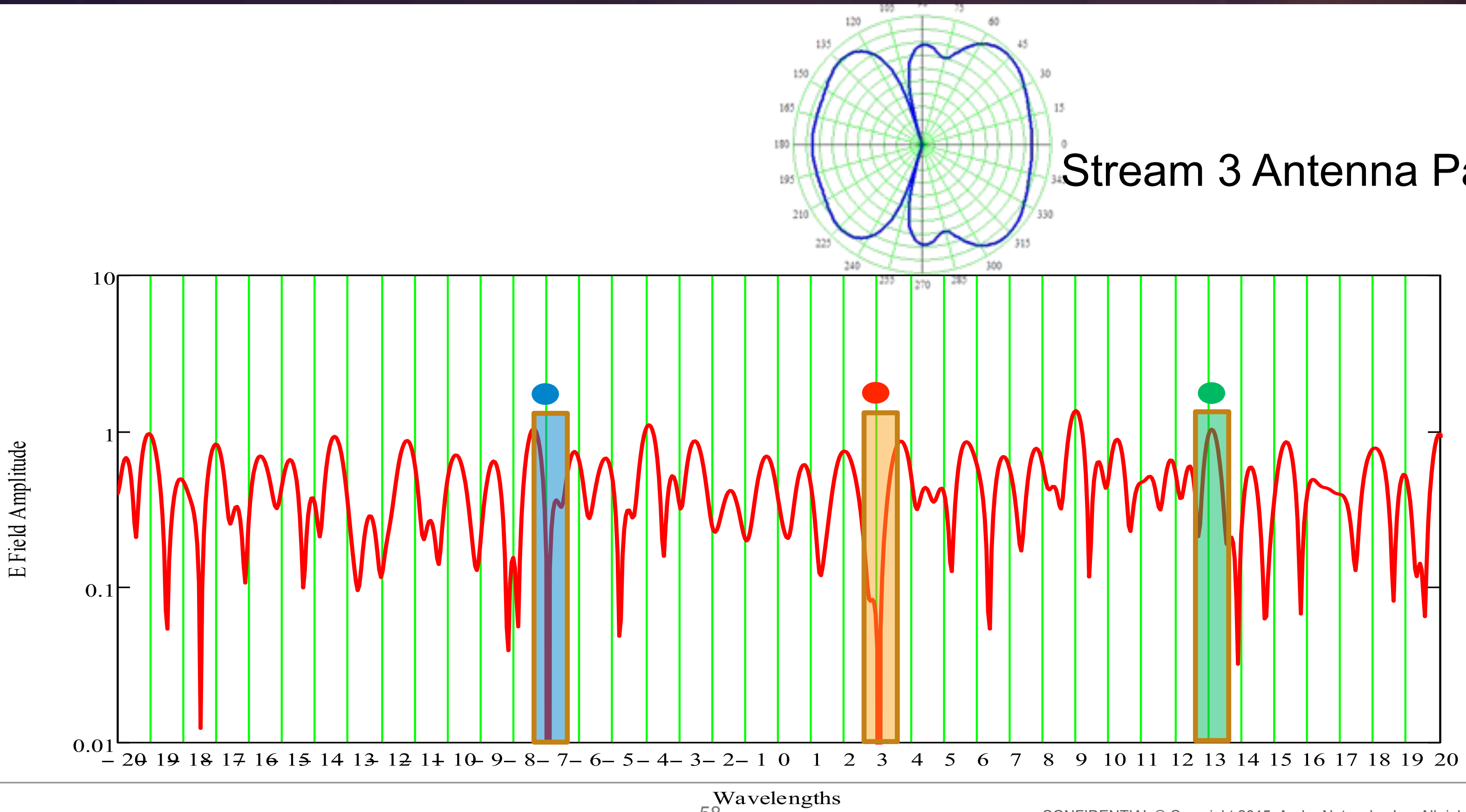


Stream 2 Antenna Pattern



Stream 3 to Client 3

Stream 3 Antenna Pattern



Practical Applications of Wave 2

Wave 2 Data Rates

	1 SSS	2 SS	3 SS	4 SS
3 SS VHT 80 MHz	433	867	1300	N/A
4 SS VHT 80 MHz	433	867	1300	1733
3 SS VHT 160 MHz	867	1733	2600	N/A
4 SS VHT 160 MHz	867	1733	2600	3466

TCP Throughputs

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	1 SS	2 SS	3 SS	4 SS
3 SS VHT 80 AP	303	607	910	N/A
4 SS VHT 80 AP	303	607	910	1213
3 SS VHT 160 AP	607	1213	1820	N/A
4 SS VHT 160 AP	607	1213	1820	2426

- 70% of data rate is best case throughput for wireless TCP traffic.
- Throughput is lost to:
  - TCP traffic
  - Management traffic
  - Assuming best SNR and single client

MU-MIMO Best Case Throughputs

- ~75% efficiency for 1 SS clients
- ~65% efficiency for 2 SS clients
- Efficiency goes down from there.
- 3 SS + 1 SS is less efficient than separately serving to 3 SS and 1 SS
- MU-MIMO has client side dependancies

MU-MIMO	1 SS clients	2 SS clients
3 SS VHT 80 AP	683	622
4 SS VHT 80 AP	910	789

MU-MIMO	max 1 SS clients	Max 2 SS clients
3 SS VHT 160 AP	1365	1244
4 SS VHT 160 AP	1820	1578

What does that mean for 11ac wave 2?

MU-MIMO efficiency means we see pretty much the same max real-world throughputs as wave 1

MU-MIMO allows the network to reach max throughput much more often

FCC opening up spectrum is critical to realize the potential of 160 MHz channels

Real world throughputs will be brought down from best case by:

- Client capability mix (11n and non-MU-MIMO devices)
- Client location distribution (weak SNR)
- Client count (air contention increases with number of clients)

Do I need 2.5 gbps for wireless?

Short answer: No.

Long Answer:

- > 1gbps will be needed at some point, but we aren’t there yet.
- No IEEE standard for 2.5 gbps
  - Limited investment protection
  - Potential wired and wireless interop issues
- Real world throughputs with 80 MHz channels will not require >1 gbps
- Wired traffic is full duplex, wireless is half
- 2.5 gbps carries a large price premium today

AMSDU/AMPDU

Deployment recommendations

VRDs are the place to start

- RF and Roaming Optimization for 11ac

Deployment recommendations

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Feature	Recommended Value
Transmit Power (dBm)	**Open Office:** 5 GHz: Min 12/Max 15 2.4 GHz: Min 6/Max 9 **Walled office or Classroom**: 5 GHz: Min 15/Max 18 2.4 GHz: Min 6 /Max 9
Channels	80 MHz channels can be used in green field deployments. U-NII-2 and U-NII-2e (DFS) channels must be used when operating on 80 MHz channels. Remove channel 144 from list.
AirTime Fairness	Fair Access
Data Rates	802.11 a & g: Basic rates:12,24 802.11 a & g transmit rates: 12,24,36,48,56
Beacon Rate (Mbps) By default lowest	For both 802.11a and g radio use 12 or 24.
Multicast rate optimization	Enable

aruba NETWORKS

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THANK YOU