BHW Technologies (博泓微科技有限公司)

RF Chips & Beyond

Advanced RF IC, Antenna, Filter, RF Front-End and Wireless System Solutions

BHW AppNote #025

Improving Range and Throughput of 2.4GHz Wi-Fi & IoT with BHWR250 Dual-Slot Quasi-Diversity Antenna

Rev. 3.3

www.bhw-tech.com

BHWR250 2.4GHz Dual-Slot Antenna

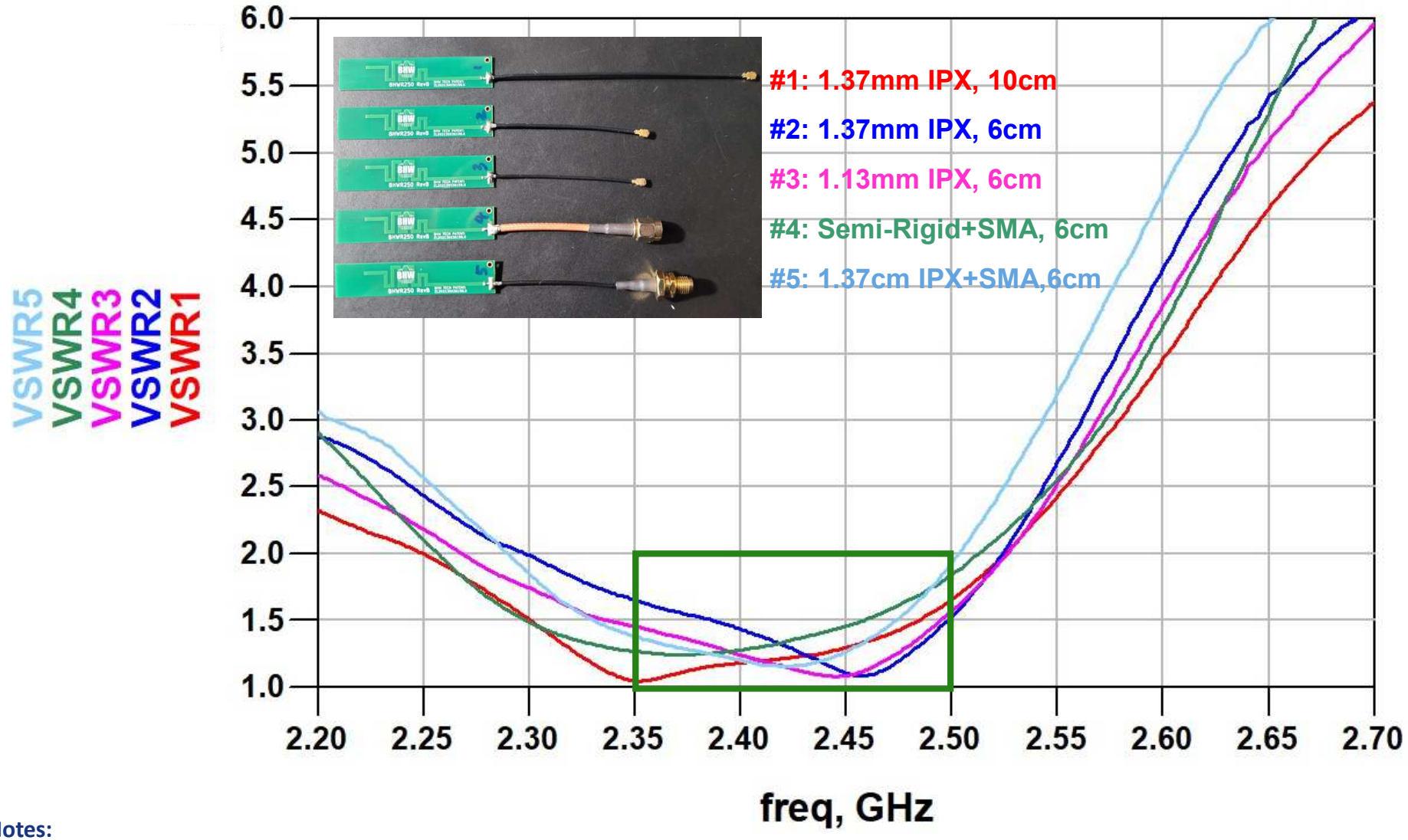
Product Overview:

- Patented Two-Element Slot Array Architecture
- 2.35-2.5GHz Operation Frequency Range
- VSWR < 2:1 over 2.35-2.5GHz
- Near-Omni Radiation Pattern in Horizontal Plane
- Gain: ~3dBi
- High Efficiency: 60%
- Stable VSWR over Housing/Cabling Effects
- Compact 12x57x0.6mm for IPX/UFL Cable Assembly
- Suitable for Replacing External Antennas in Wi-Fi Routers and other Products without Compromise in Performance
- Unique Quasi-Diversity Capability without Using RF Switch

Applications:

- Wi-Fi MU-MIMO Solutions
- Wi-Fi 3/4/5/6 Routers/Repeaters
- Wi-Fi Modules/Data Links
- 2.4GHz Audio/Video Streaming
- Long-Range ZigBee/Thread/Matter, IoT Solutions
- Generic 2.4GHz Radio Designs
- FPC/LDS Antenna Alternative with Minimum Frequency Shift

BHWR250 VSWR for Difference Cable Assemblies

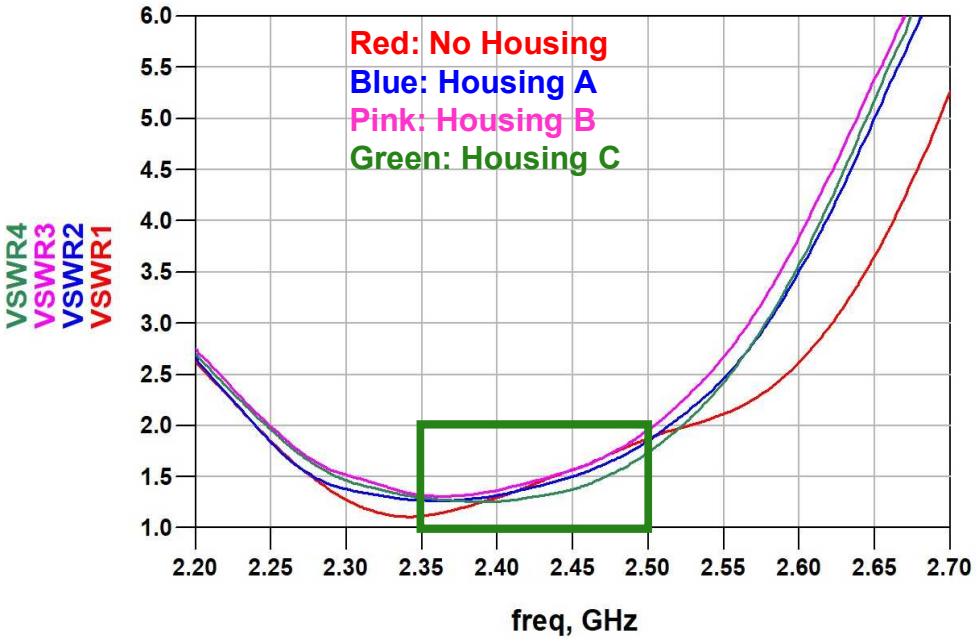


Notes:

- Different cable assemblies of BHWR250 result in slight variation in VSWR, due to non-ideal interface impedance and hand soldering
- VSWR<2:1 over 2350-2500MHz for all cases
- VSWR changes slightly after antenna is inserted into housing, with center frequency shifted lower typically, but only slightly in most cases

BHWR250 VSWR with Minimum Housing Effects

Input VSWR Including Housing Effect

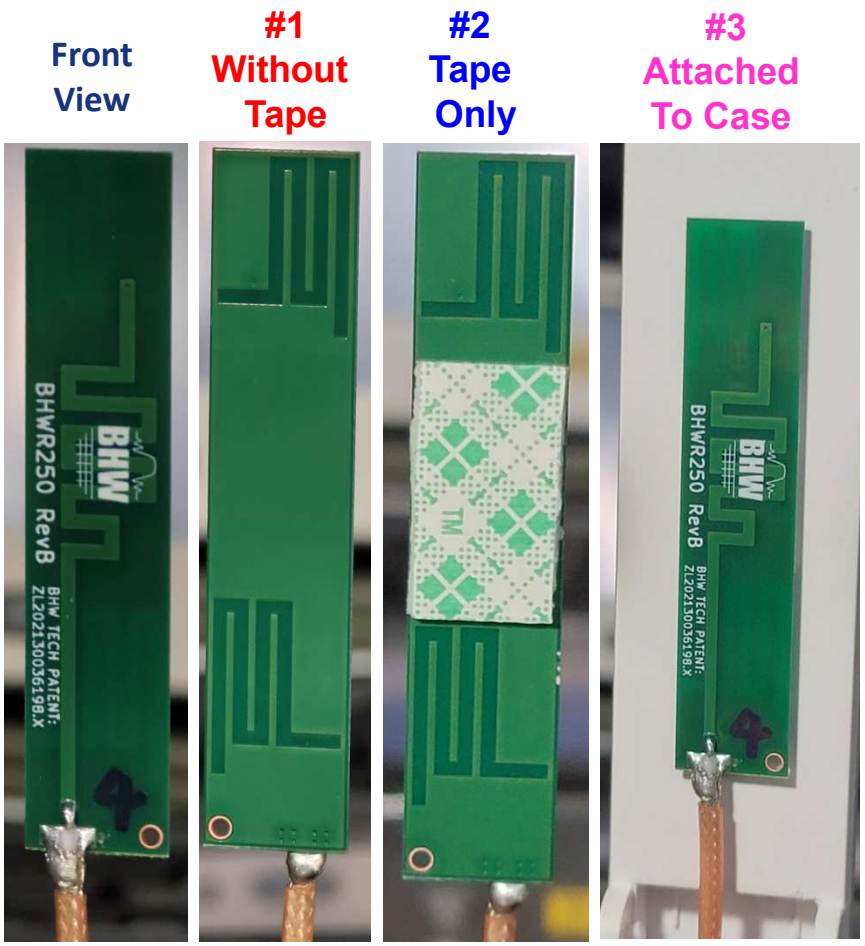


Notes:

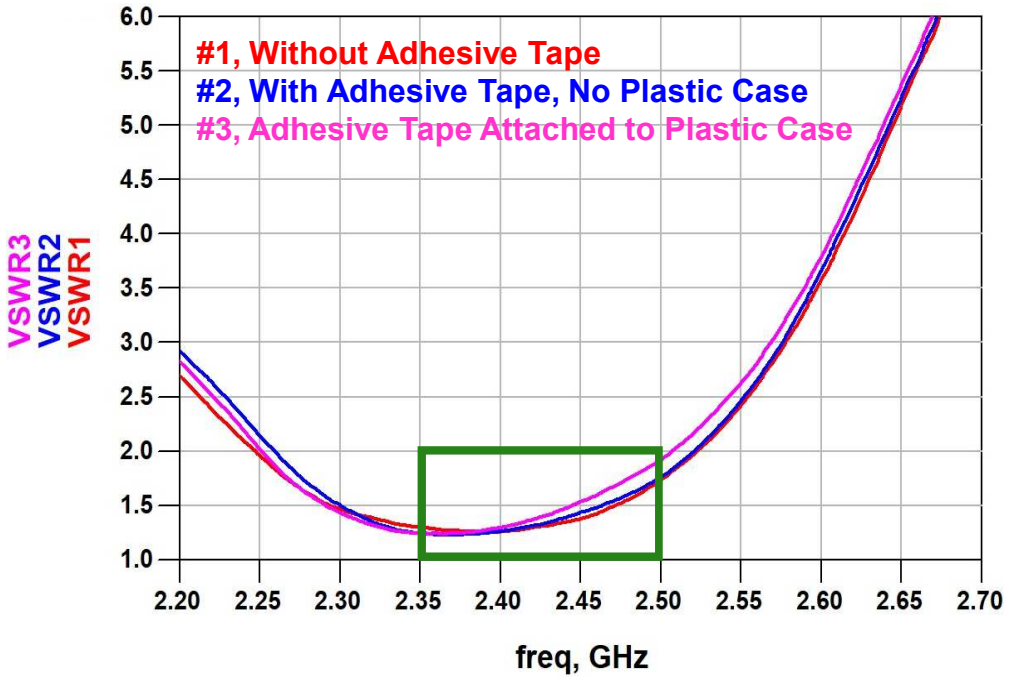
- Semi-Rigid SMA cable was soldered to BHWR250
- Length of semi-rigid cable is ~6cm
- VSWR<2:1 over 2350-2500MHz
- No significant change in VSWR was observed by applying three types of housings to BHWR250

BHWR250 for FPC/LDS Antenna Alternatives

Test Samples



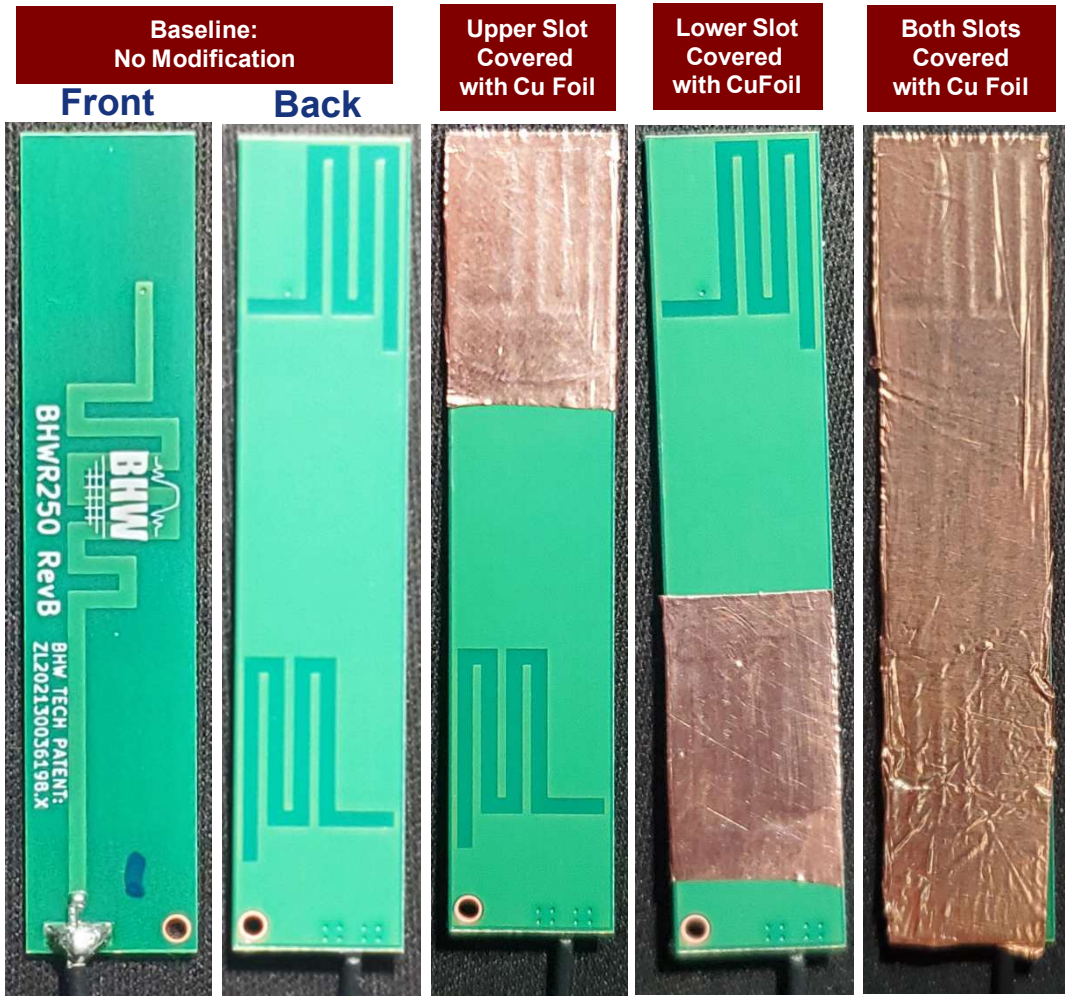
Input VSWR with/without Plastic Case

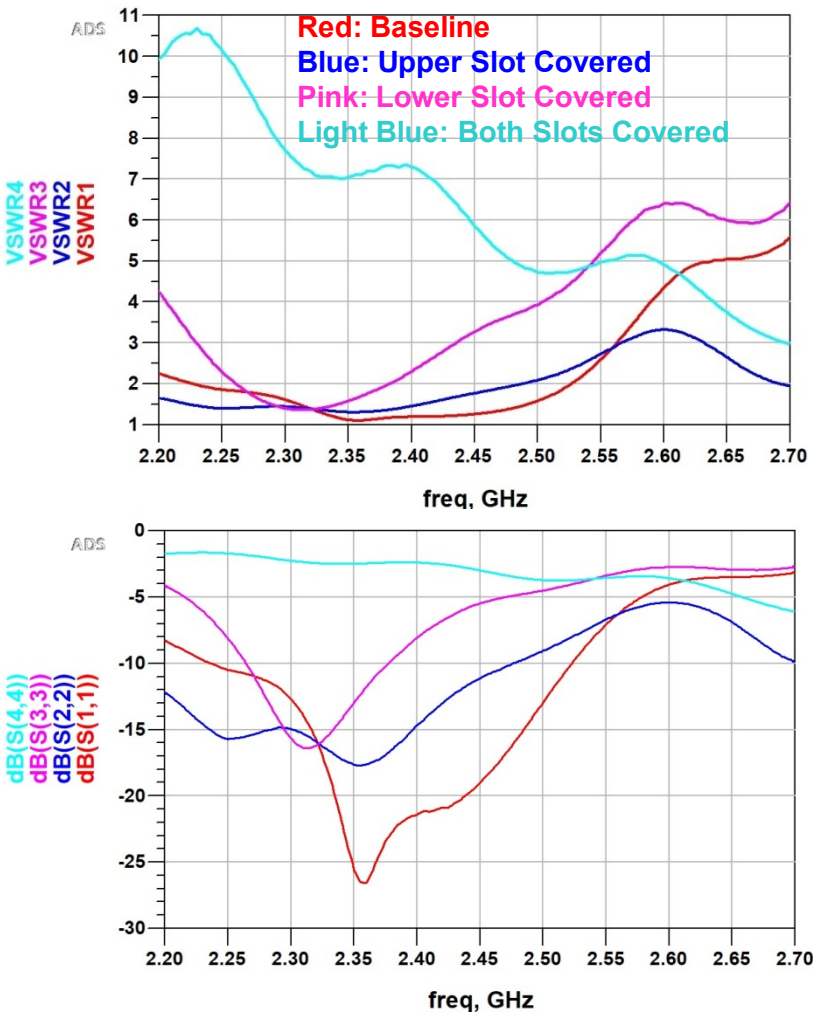


Notes:

- Adhesive tape with size 12x20x1.3mm was added to the ground area in the back side of BHWR250
- To ensure minimum shift in antenna performance, please select adhesive tape with minimum thickness of 1mm
- Adhesive tape should not block the radiating slots to guarantee optimal antenna performance
- VSWR<2:1 over 2350-2500MHz for all cases
- VSWR may change slightly when the antenna is attached to different types of plastic housing, but should not exceed 2:1 for most practical use cases

BHWR250 Quasi-Diversity Characteristics





Notes:

-Conventional antenna diversity requires the use of an RF switch

-BHWR250 provides some "quasi-diversity" characteristics due to its unique dual-slot design

-VSWR remains below 2:1 across 2.35-2.5GHz when the upper slot is covered and shorted completely with copper foil

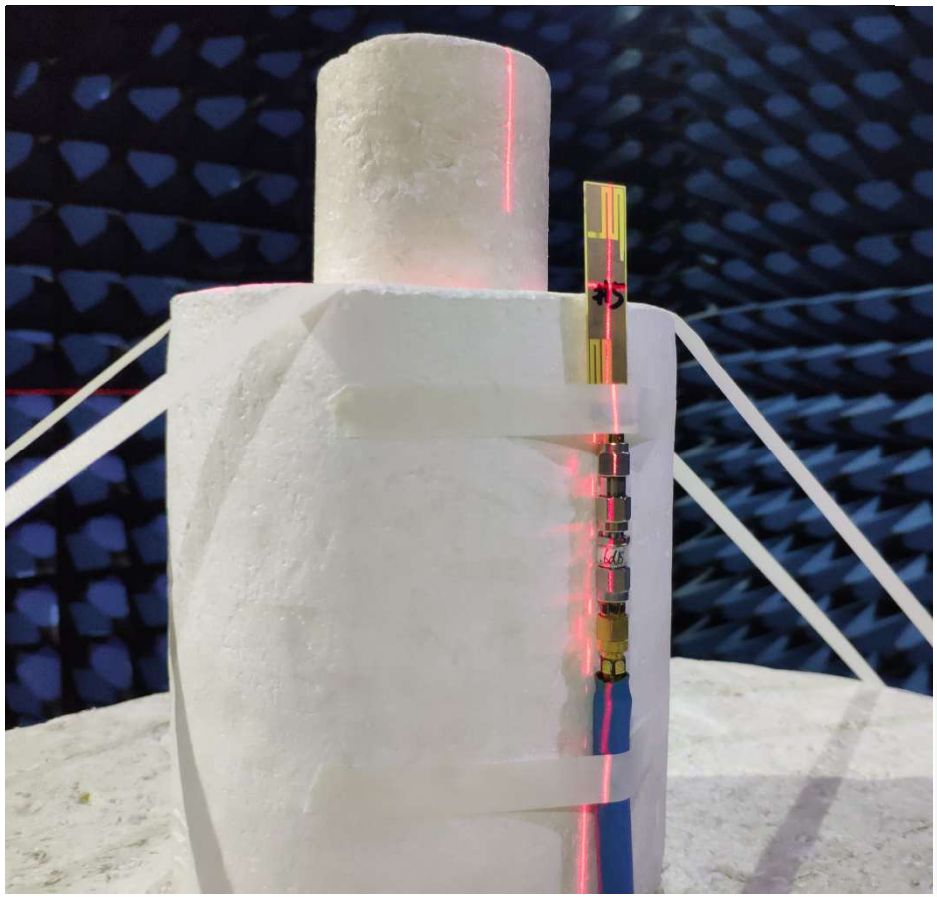
-VSWR shows some degradation but the antenna is still reasonably well matched when the lower slot is covered

-VSWR is degraded significantly when both slots are covered, as expected. However, S11~-3dB indicates partial radiation from the feeding meander lines, which might help improve RF link quality in some use cases with severe multipath effects

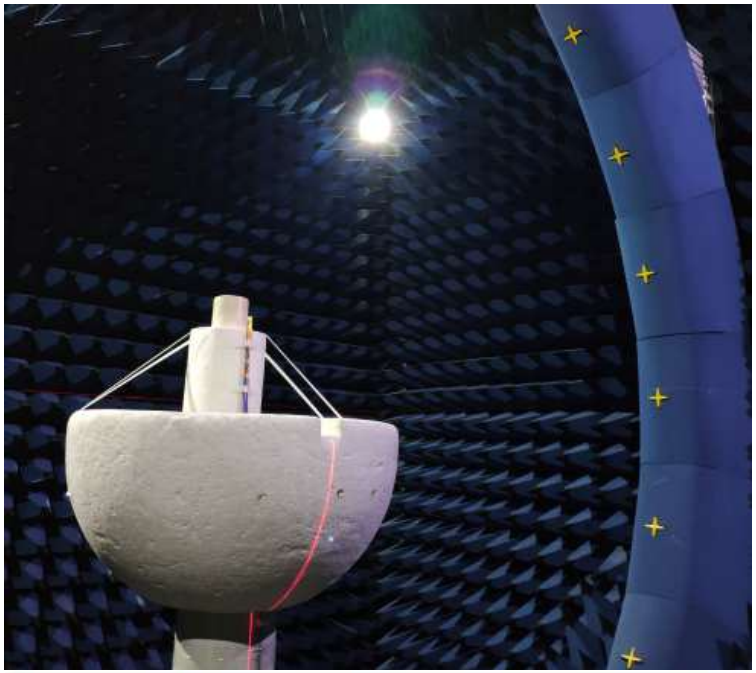
BHWR250 Radiation Pattern: Test Setup

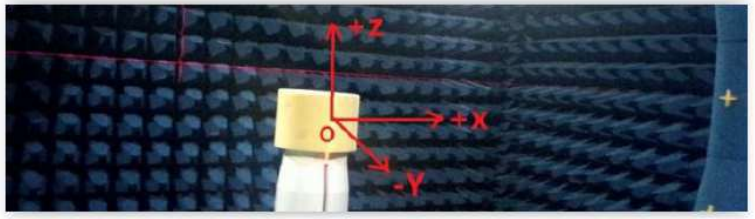
Antenna Orientation

BHWR250 Test Setup



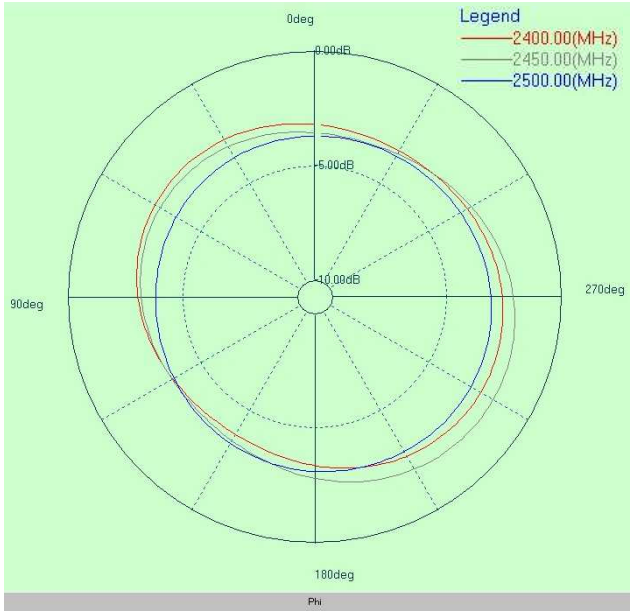
Anechoic Chamber Coordinate System





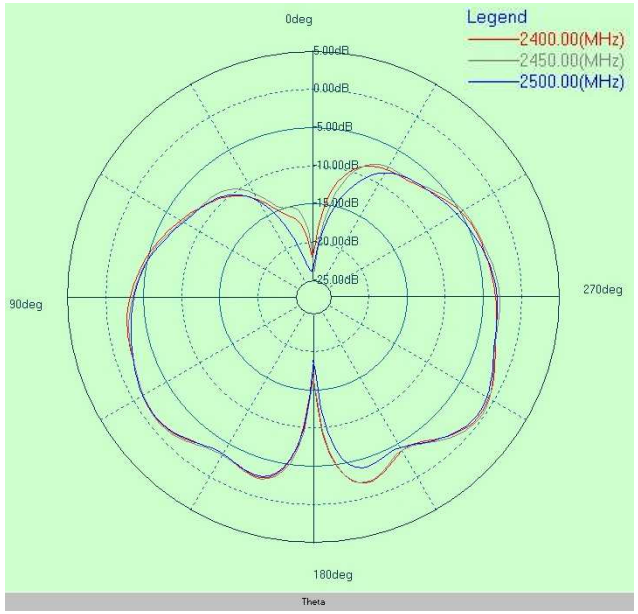
BHWR250 Radiation Pattern: 2D Plots

BHWR250
XOY-Plane Cut



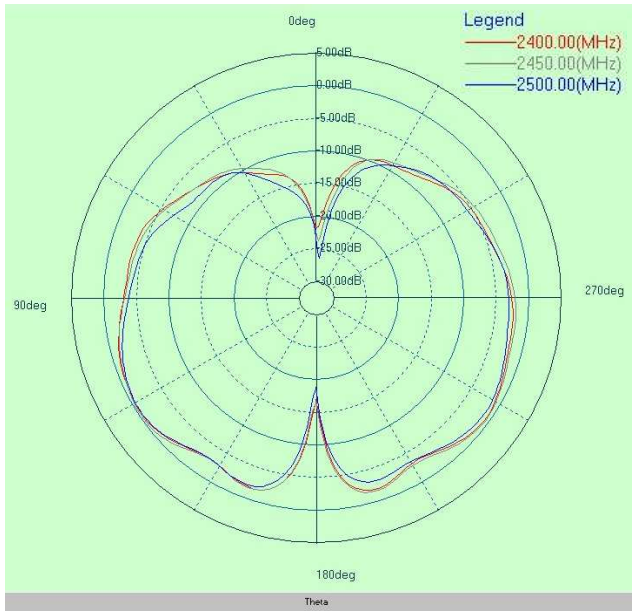
Near-Omnidirectional Radiation in Horizontal Plane (XOY)

BHWR250
XOZ-Plane Cut



Slightly Compressed Radiation in Vertical Plane (XOZ)

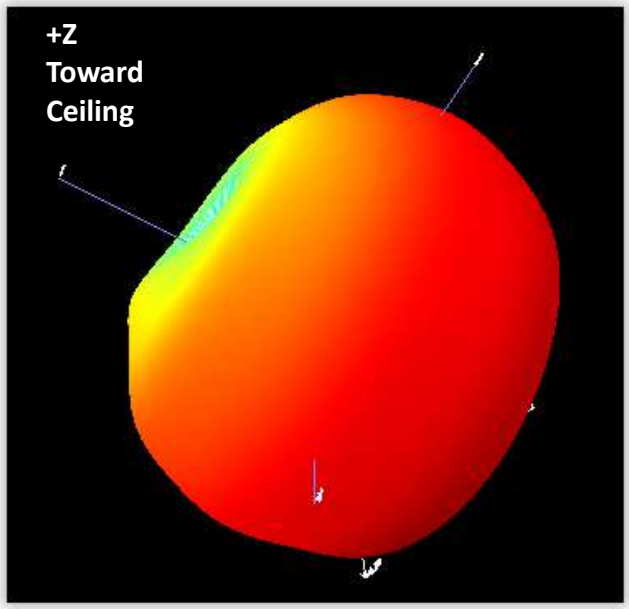
BHWR250
YOZ-Plane Cut



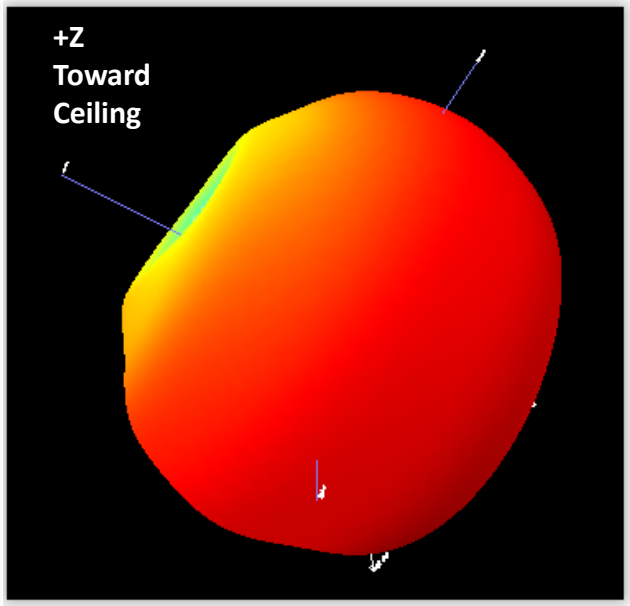
Slightly Compressed Radiation in Vertical Plane (YOZ)

BHWR250 Radiation Pattern: 3D Plots

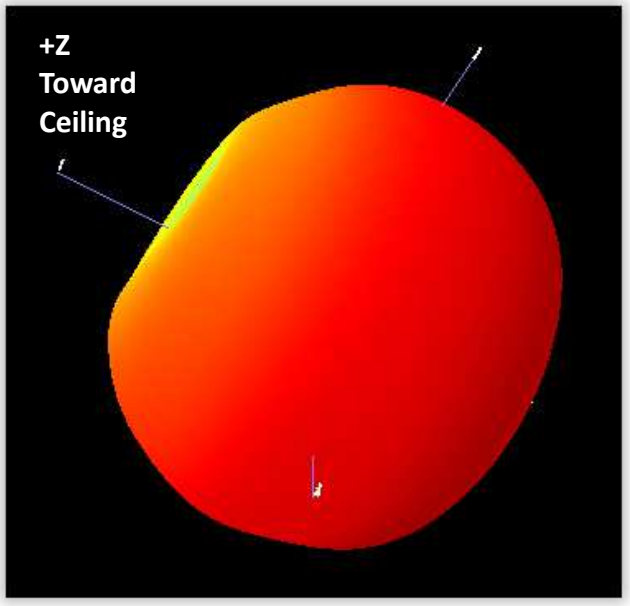
BHWR250
2400MHz



BHWR250
2450MHz

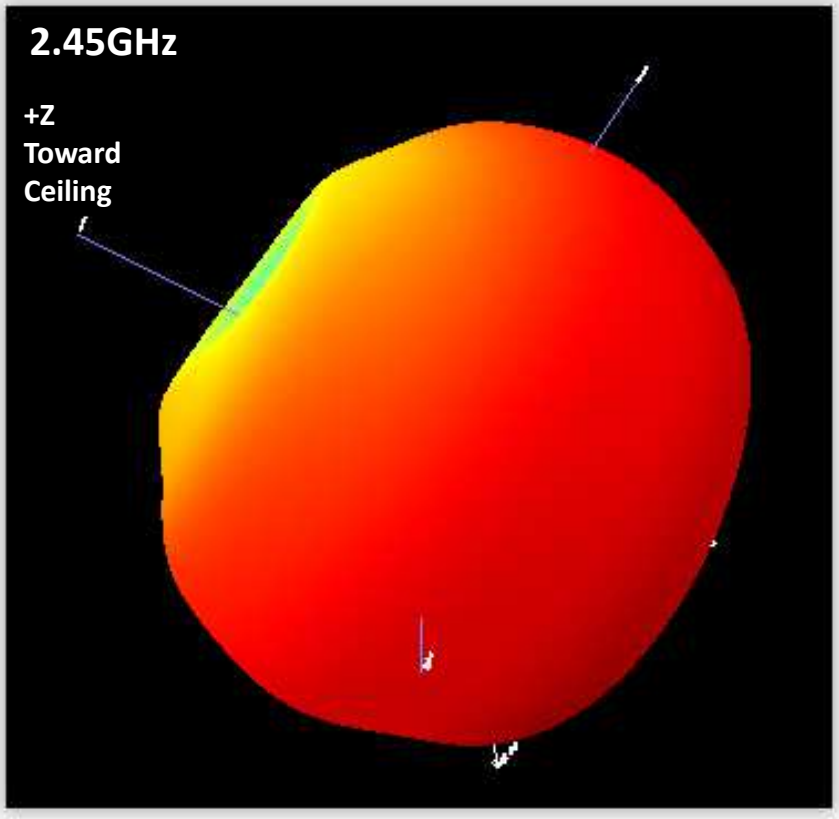


BHWR250
2500MHz

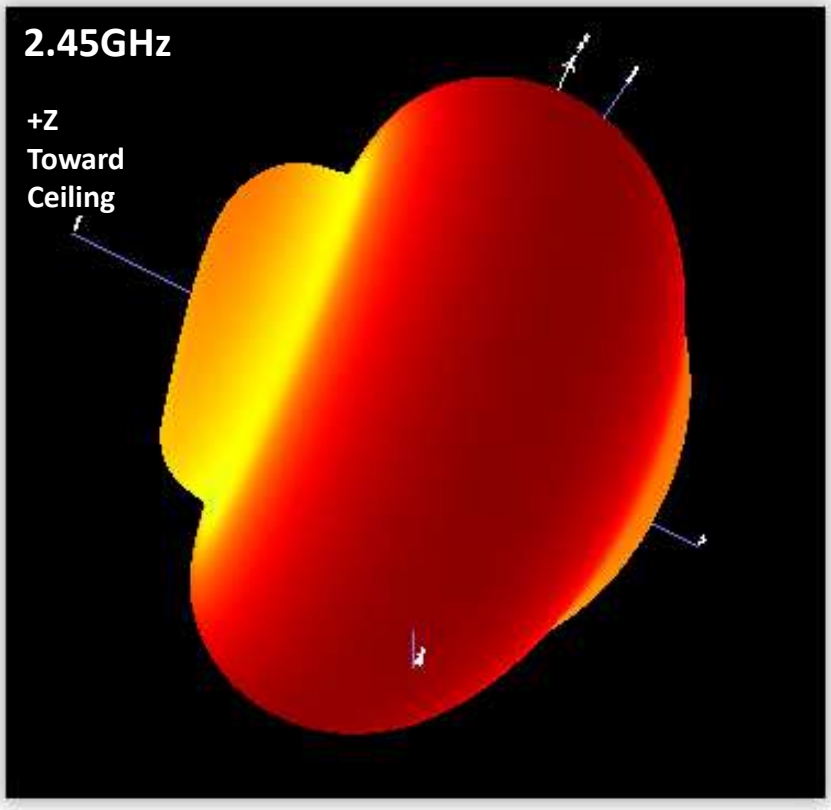


BHWR250 3D Radiation Pattern vs Competition

BHWR550
12x57mm



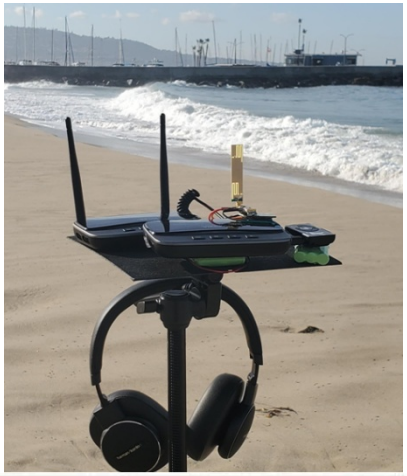
Vendor L
14x200mm



Note: The competitor "high-gain" antenna has some grating lobes (dips) in vertical directions, which may impact throughput at certain angles/locations even short in distance. In comparison, BHWR250 was engineered to provide a much smoother radiation pattern and better signal distribution/coverage, enabling stable high-throughput mode of operation, and improved overall user experience.

2.4GHz Audio Streaming Range Extension Case #1

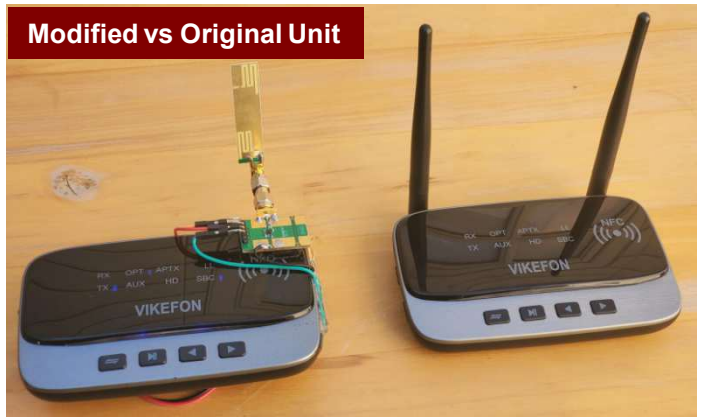
- Test Platform: Qualcomm CSR8675 BLE SoC for Audio
- Mode of Operation for Test: Tx Mode
- Original RF Front-End: 3x3mm FEM + Dual-Antenna
- Modification: Replace FEM with BHWM257 (2x2mm); Replace Dual Antennas with Single BHWR250 (57mm)
- Test Setup: Tx on Tripod at ~1.5m Height. Over-the-Ear Headphone Used for Rx, Open Space, LOS.



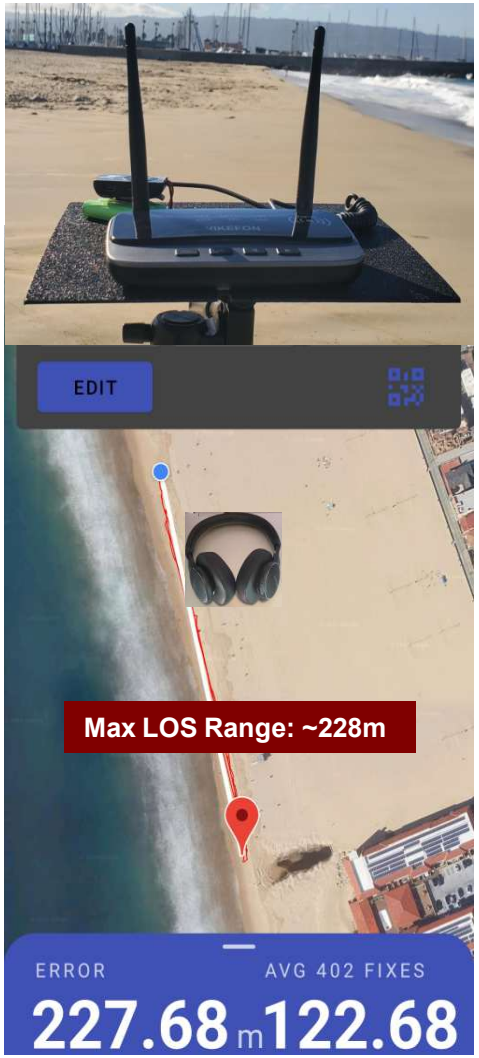
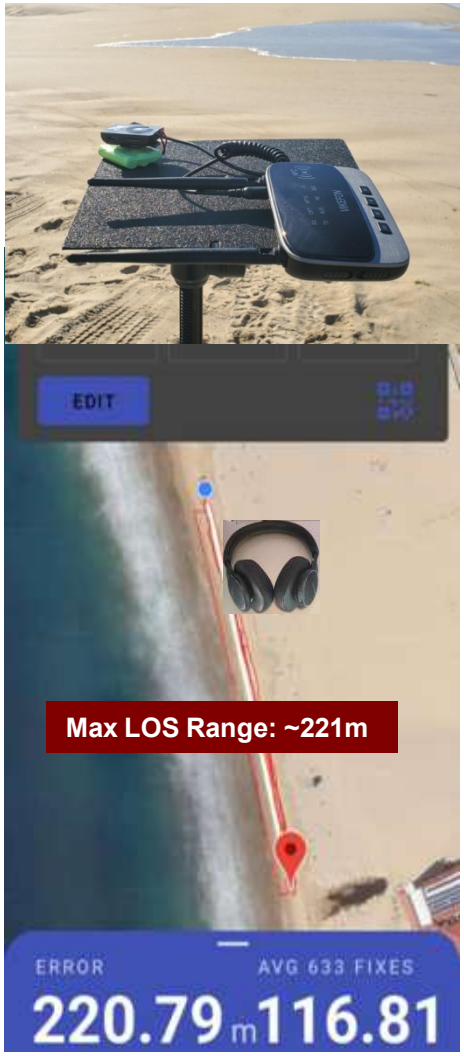
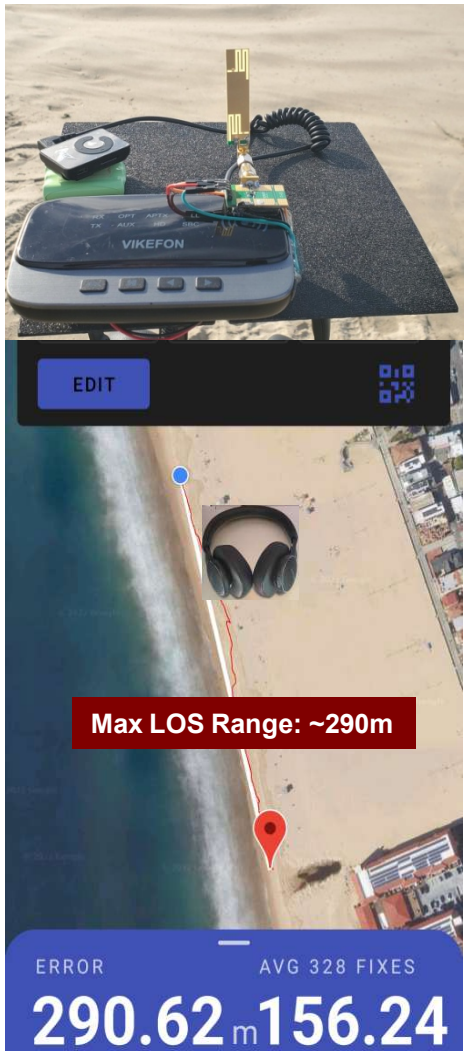
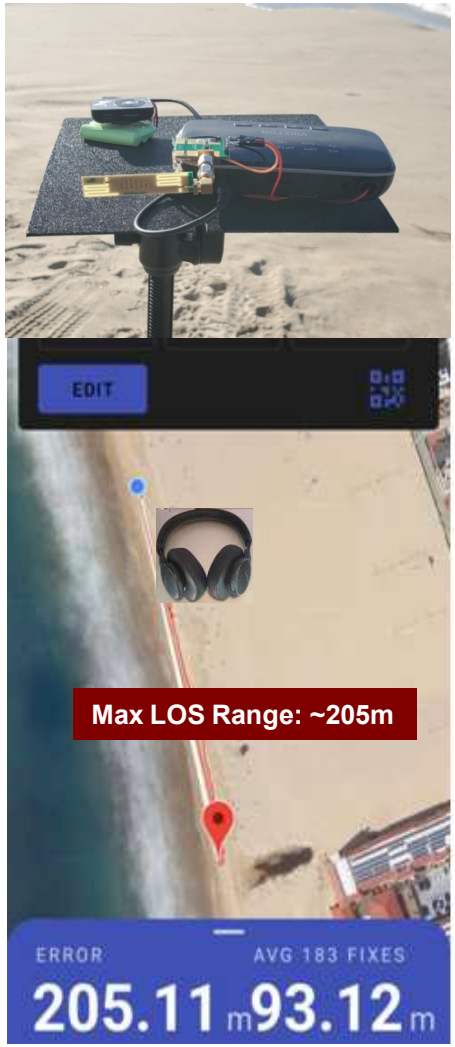
Modified Unit
BHWM257 & BHWR250 Single Antenna

Original Unit: 3x3mm FEM & Diversity Antenna

Modified vs Original Unit



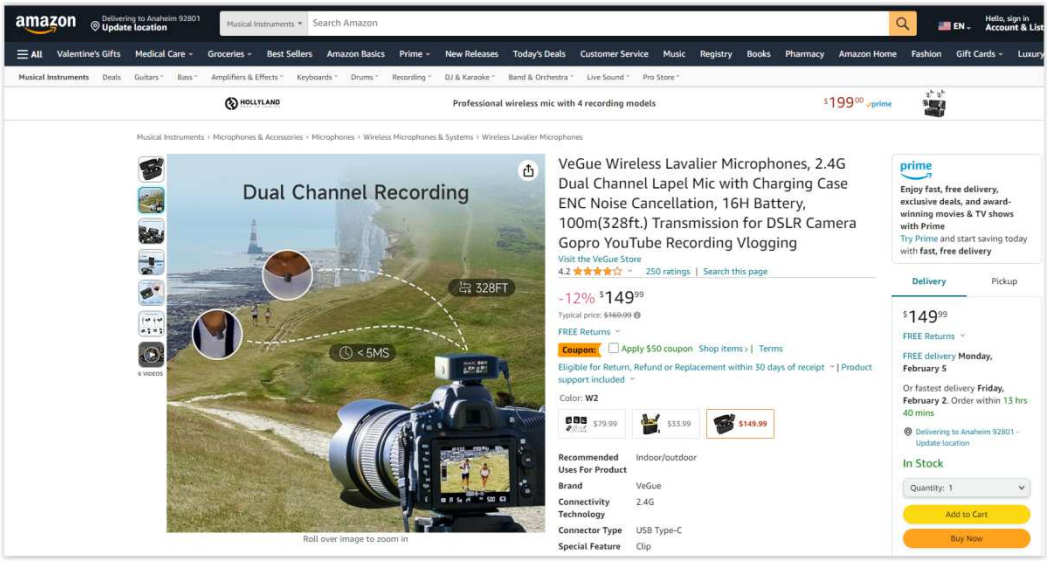
2.4GHz Audio Streaming Range Extension Case #1

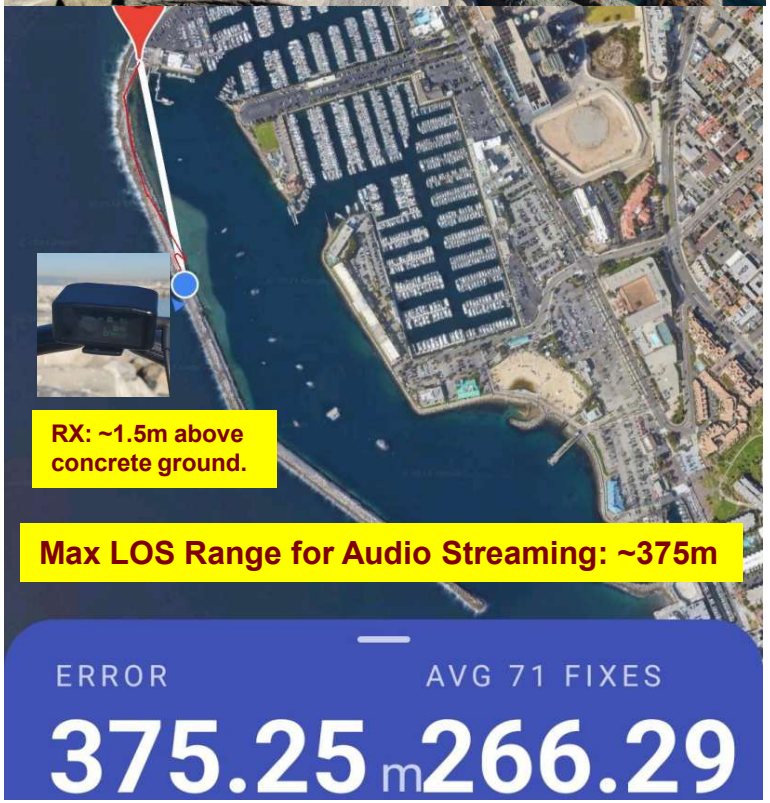
Original Unit without Modification: Antenna in Vertical Orientation	Original Unit without Modification: Antenna in Horizontal Orientation	Modified Unit with BHWM257 & BHWR250 in Vertical Orientation	Modified Unit with BHWM257 & BHWR250 in Horizontal Orientation
			
Max LOS Range: ~228m	Max LOS Range: ~221m	Max LOS Range: ~290m	Max LOS Range: ~205m
ERROR 227.68 m AVG 402 FIXES 122.68	ERROR 220.79 m AVG 633 FIXES 116.81	ERROR 290.62 m AVG 328 FIXES 156.24	ERROR 205.11 m AVG 183 FIXES 93.12 m

Comments: For much lower current consumption and smaller FEM size, and with only one compact PCB antenna instead of two longer dipoles, the BHWM257 & BHWR250 solution provides comparable range to that of the original design.

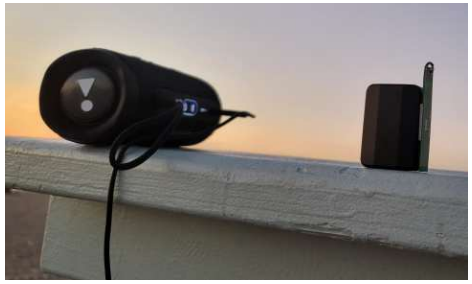
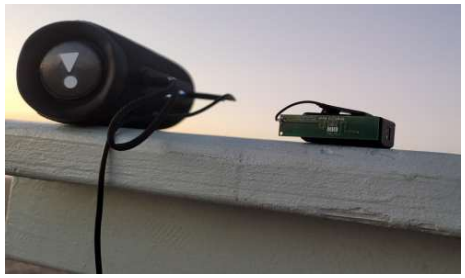
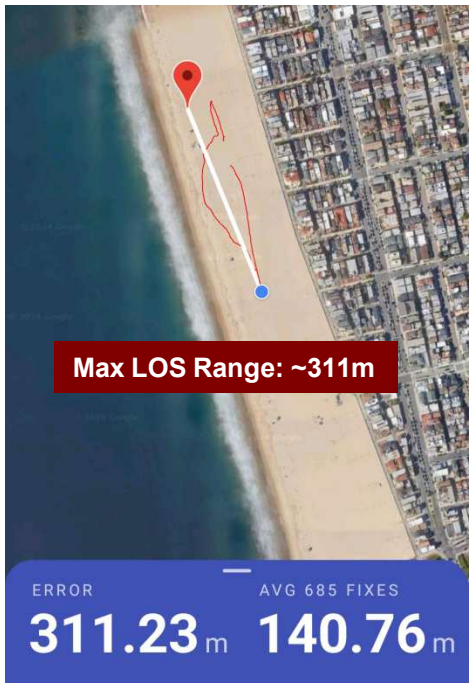
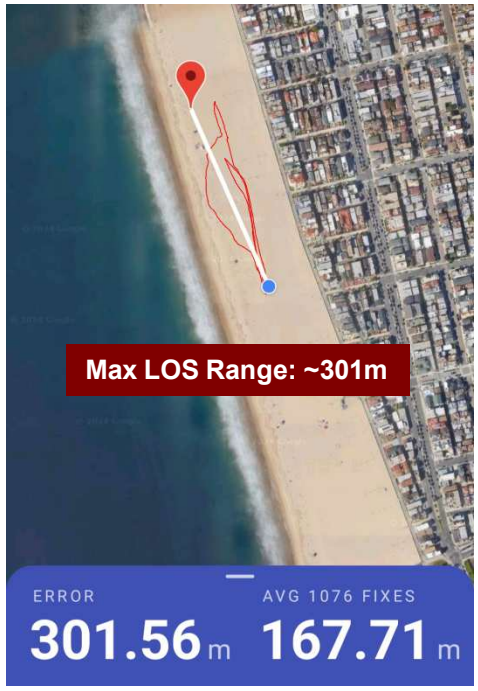
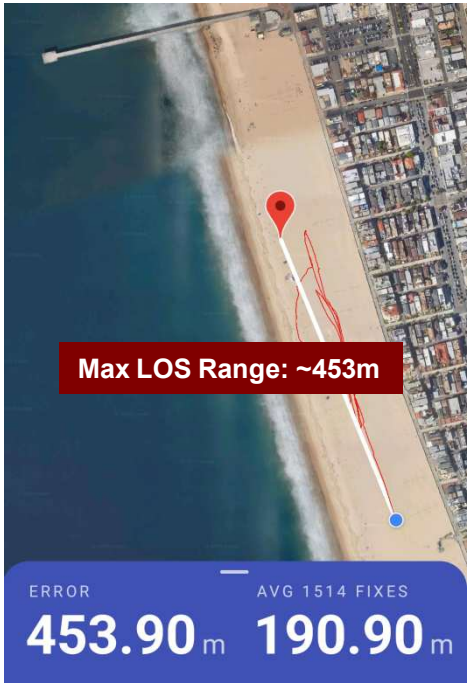
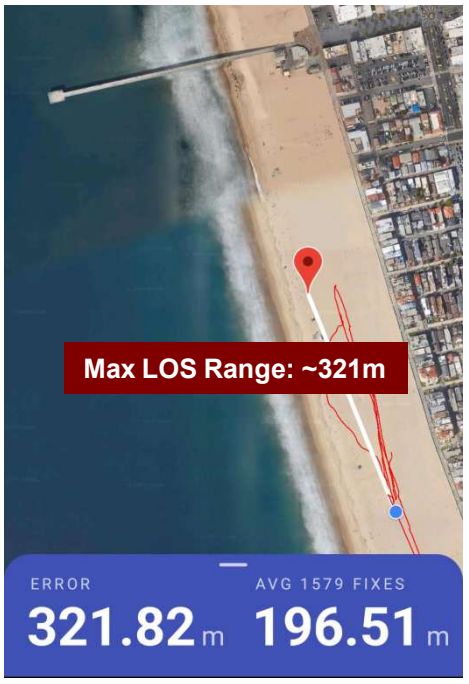
2.4GHz Audio Streaming Range Extension Case #2

Test Vehicle: VeGue W2 dual-channel long range wireless lavalier MIC with BHWM257 FEM achieving 8 hours operation life with 250mAh battery. Internal FPC antenna in TX unit (MIC) replaced with BHWR250. No modification on RX.





2.4GHz Audio Streaming Range Extension Case #2

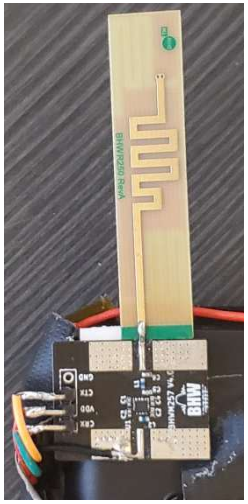
Modified TX with BHWR250 Antenna Orientation #1	Modified TX with BHWR250 Antenna Orientation #2	Modified TX with BHWR250 Antenna Orientation #3	Modified TX with BHWR250 Antenna Orientation #4
			
			

Comments: For this LOS range test, the TX unit of the VeGue W2 2.4GHz wireless microphone was replaced with BHWR250 dual-slot antenna and placed ~2m above sandy ground on a wood beam with four different antenna orienations. The RX unit was not modified and clipped to jacket ~1.5m above ground. Average Max LOS range for audio streaming for the four orientations is 346m.

2.4GHz Audio Streaming Range Extension Case #3

Transmitter: Qualcomm CSR8675 BLE SoC + BHWM257 FEM + BHWR250 Antenna

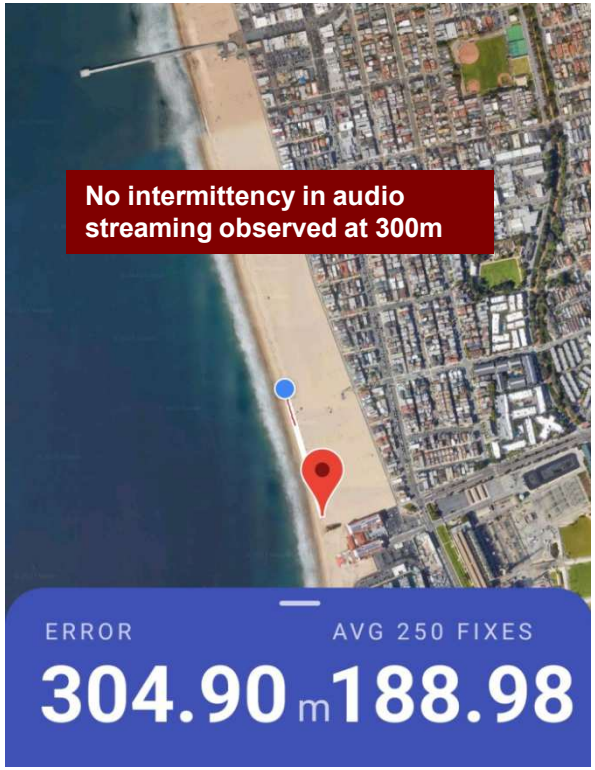
Receiver: Qualcomm CSR8675 BLE SoC + BHWM257 FEM + BHWR250 Antenna



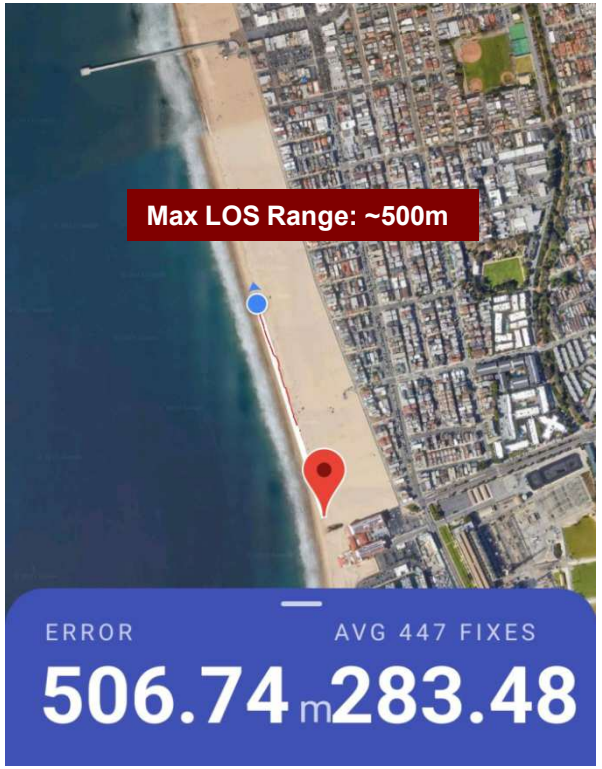
Tx: ~1.5m above ground on tripod

Rx: Held above head in walk test

No intermittency in audio streaming observed at 300m



Max LOS Range: ~500m

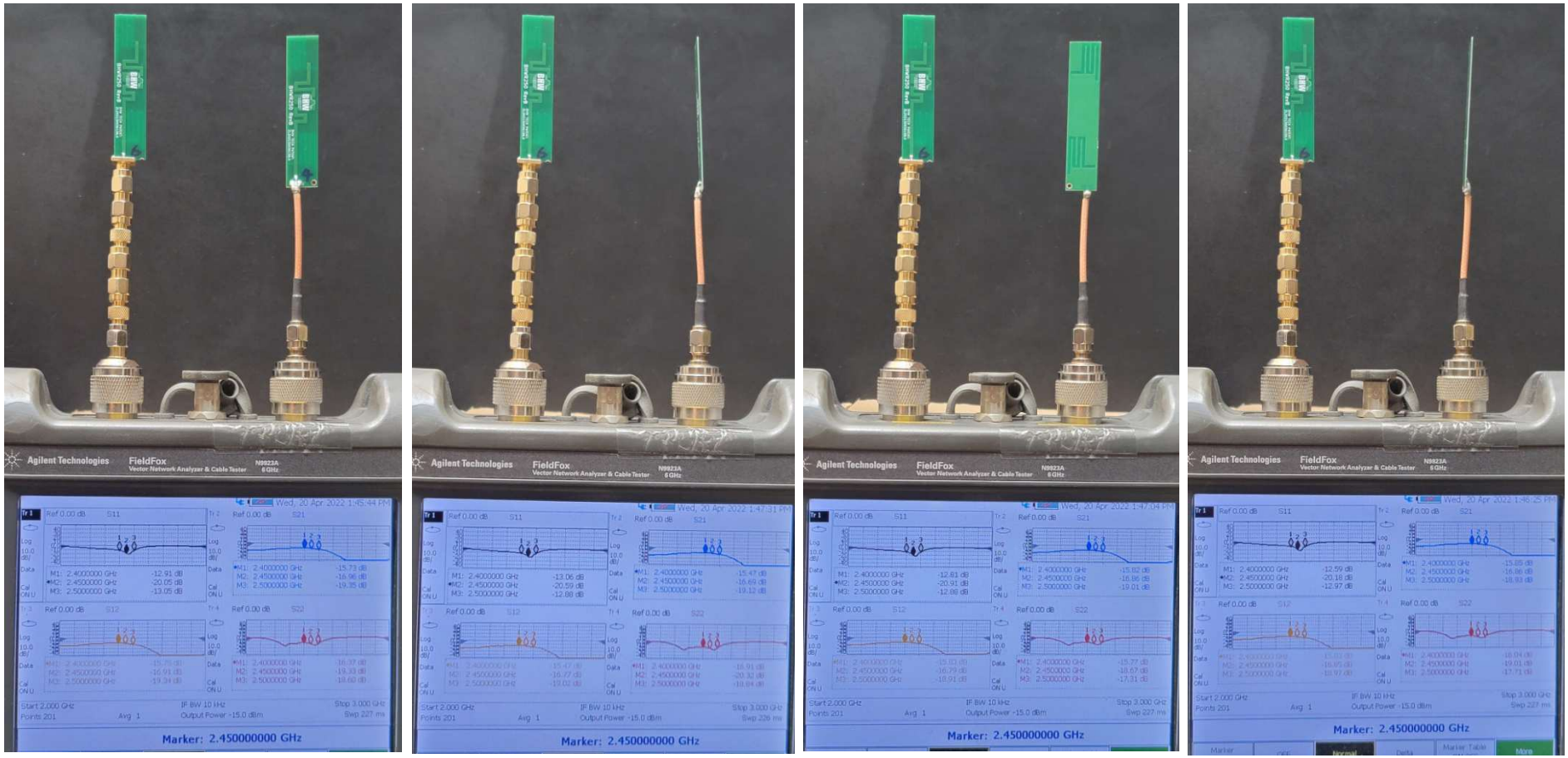


Conclusion: With both TX and RX modified with BHWM257 FEM and BHWR250 antenna, maximum LOS range of ~500m can be achieved for audio streaming.

Mutual Coupling Effects for MIMO Applications

Mutual Coupling between Two BHWR250 Antennas in Co-Polarized Positions
Fixed Antenna #6 and Rotated Antenna #4 for 4 Angles over 360 Degrees

S21=-17.0dB at 2450MHz | S21=-16.7dBat 2450MHz | S21=-16.9dBat 2450MHz | S21=-16.9dB at 2450MHz



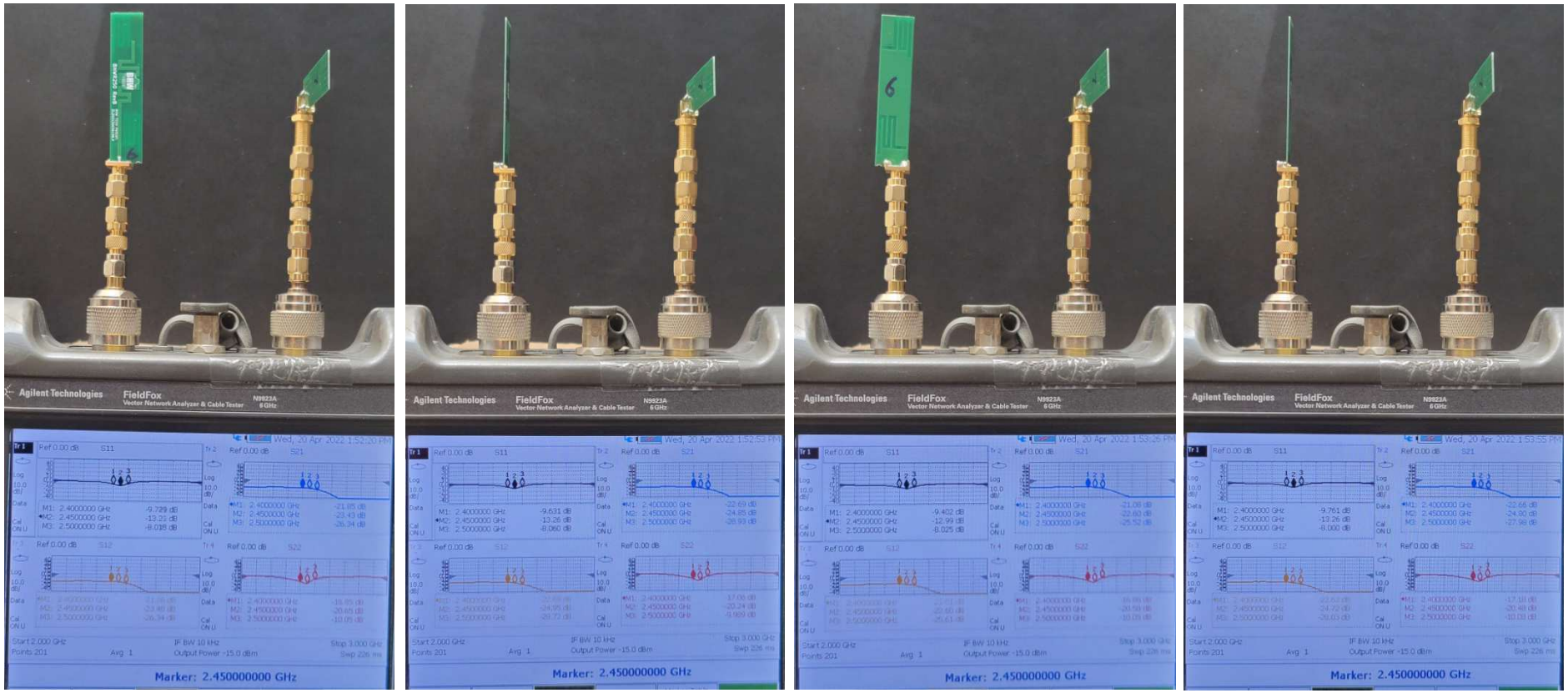
Notes:

- Use measurement of S21 with VNA as a simplified test methodology to evaluate mutual coupling between two antennas.
- Distance between RF Port 1 & 2 of Agilent FieldFox is ~6.7cm (slightly over half wavelength of 2.45GHz (6.1cm).
- Coupling levels between to BHWR250 antennas at this separation is around -17dB. For reference the coupling level between two stock dipole antennas commonly used on Wi-Fi routers (~20cm in length or ~3x longer that of BHWR250) is around -15dB.
- Very minor change in mutual coupling over 360 deg rotation indicates near-omnidirectional radiation pattern, consistent with antenna chamber test results.

Mutual Coupling Effects for MIMO Applications

Mutual Coupling between Two BHWR250 Antennas in Cross-Polarized Positions Fixed Antenna #7 and Rotated Antenna #6 for 4 Angles over 360 Degrees

S21=-24.3dB at 2450MHz | S21=-24.9dBat 2450MHz | S21=-22.6dBat 2450MHz | S21=-24.8dB at 2450MHz



Notes:

-Mutual coupling level between two BHWR250 antennas in perpendicular orientations (cross-polarized) measured 6-7dB lower than that of parallel orientations (co-polarized), indicating moderately linear polarization of the antenna.

-As reference the mutual coupling between two 20cm long stock dipole antennas in perpendicular orientations and identical separation measured around -33dB, closer to pure linear polarization, mainly due to ~3x larger in antenna length.

-Depending on use cases, the existing of some cross-polarization component as that of BHWR250 may be advantageous since it functions as soft "polarization diversity" to mitigation RF signal fading in highly reflective environments.

Comments on BHWR250 Mutual Coupling for MIMO

- For Wi-Fi MIMO systems such as 2x2, 4x4, the ideal antenna element for beam-forming is one with perfectly omni-directional radiation pattern across all channels in the frequency band of operation, which unfortunately does not exist in real world

- A low-/moderate-gain antenna with low mutual coupling and stable, near-omnidirectional radiation pattern in the horizontal plane across all frequency channels is a good candidate for practical Wi-Fi MIMO systems

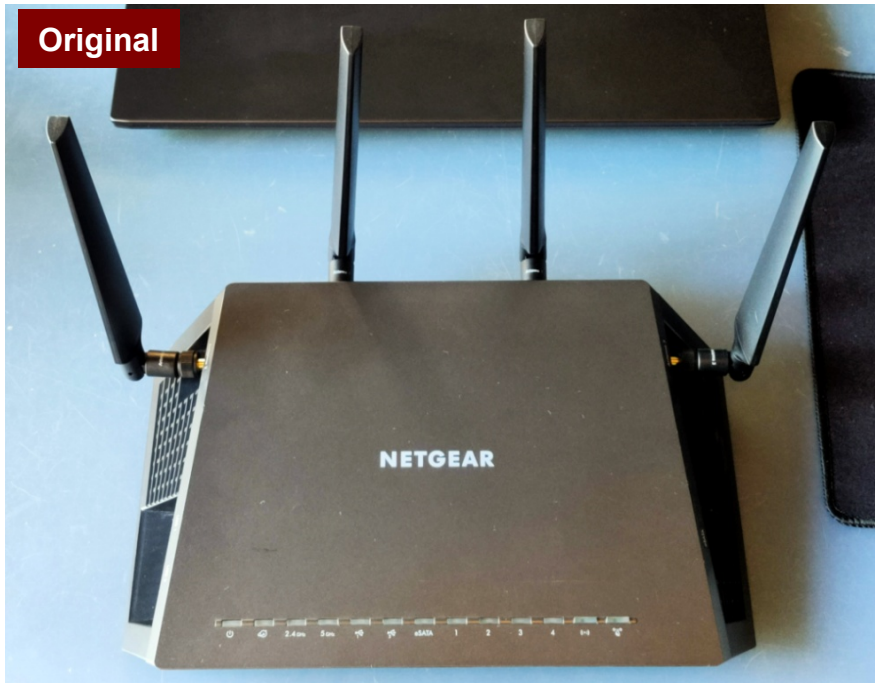
- BHWR250 (and its companion BHWR550 for 5GHz band) was engineered exactly based on the above concept and design methodology

- Compared to some of the state-of-art MIMO antennas used in Wi-Fi routers, BHWR250 is significantly more compact in size, roughly 1/3 in height, yet it demonstrates stable and well-defined near omni-directional radiation patterns in the horizontal plane

- Many commonly seen Wi-Fi router antennas were designed for relatively high gain (e.g, 5-6dBi), which may not be best for MIMO systems since the high gain results in increased level of mutual coupling between adjacent antennas (for identical spacing). With a moderate gain of ~3dBi and stable VSWR and radiation patterns over the entire 2.4GHz band, BHWR250 should be more suitable for MIMO, since it has in 2-3dB lower mutual coupling between adjacent antennas with same spacing when compared to much larger, higher gain diople antennas ~3x in height

BHWR250 Wi-Fi Signal Strength Benchmark #1

Replacing Antennas on Netgear Nighthawk X4S R7800 with BHWR250



Notes:

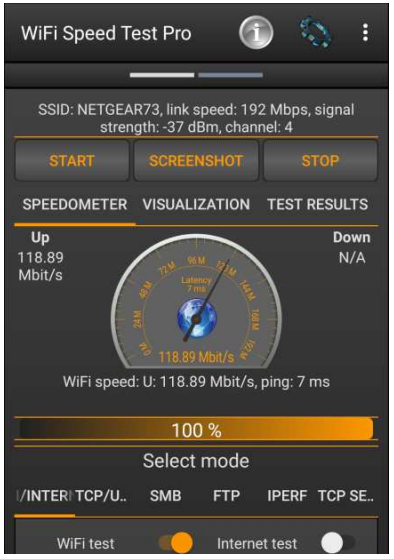
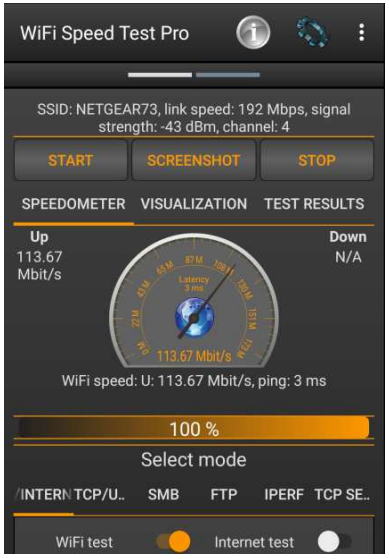
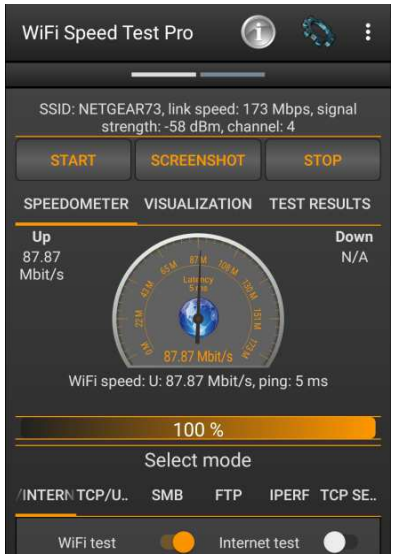
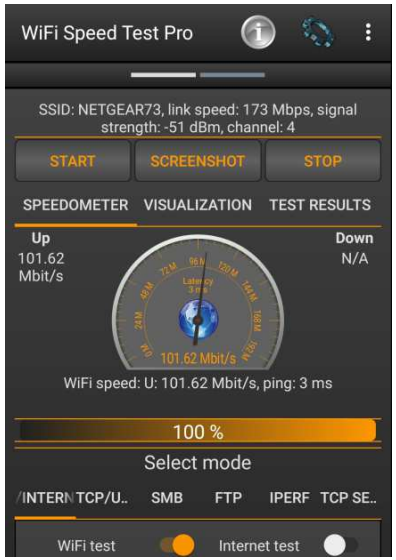
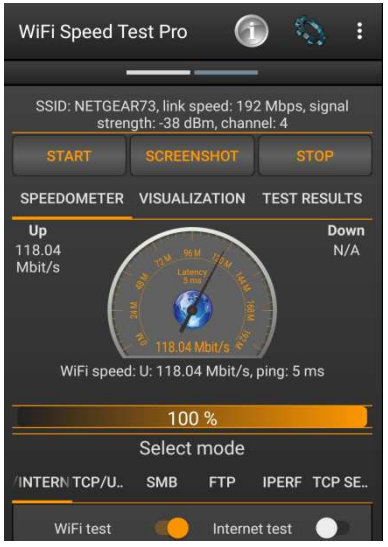
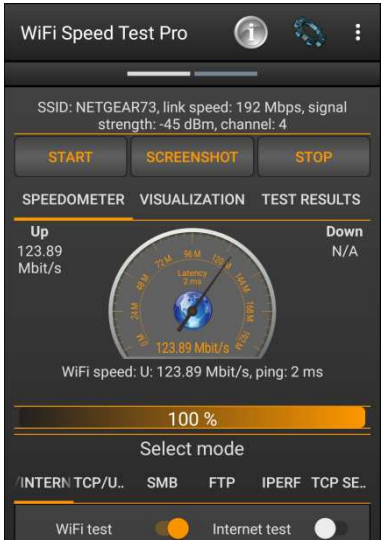
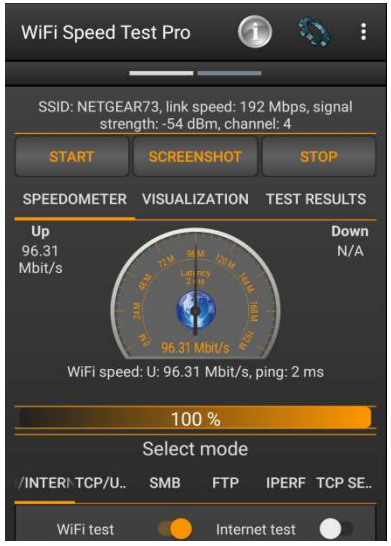
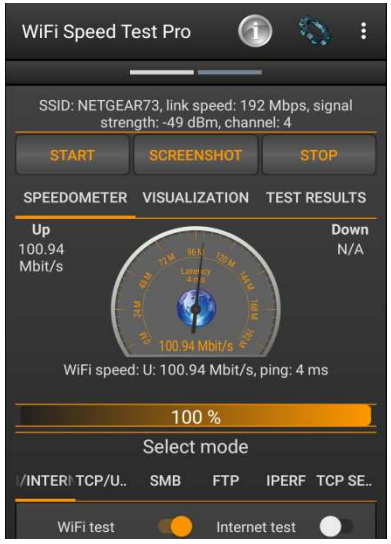
- **Netgear Nighthawk X4S R7800 is dual-band 4x4 MU-MIMO router with four dual-band antennas, each ~180mm in total height.**
- **The four original antennas were replaced by BHWR250 (12x57mm) for benchmark test of WiFi-to-LAN throughput in the 2.4GHz band.**
- **Netgear R7800 was connected to a laptop with Ethernet cable to be used as TCP server for WiFi-to-LAN throughput test.**
- **WiFi Speed Test Pro (Android APP) on Samsung Galaxy S10e was used to test WiFi speed at various locations.**

	NETGEAR R7800
CPU	Qualcomm dual-core IPQ8065 Internet Processor @ 1.7 GHz
Switch	Qualcomm Atheros QCA8337
RAM	512 MB
Flash	128 MB
2.4 GHz Radio	- QCA9984 4x4 MU-MIMO 802.11ac radio - Skyworks SE2623L 2.4 GHz power amp (x4)
5 GHz radio	- QCA9984 4x4 MU-MIMO 802.11ac radio - RFMD RFPA5542 5 GHz PA module (x4)

Source: SmallNetBuilder.com

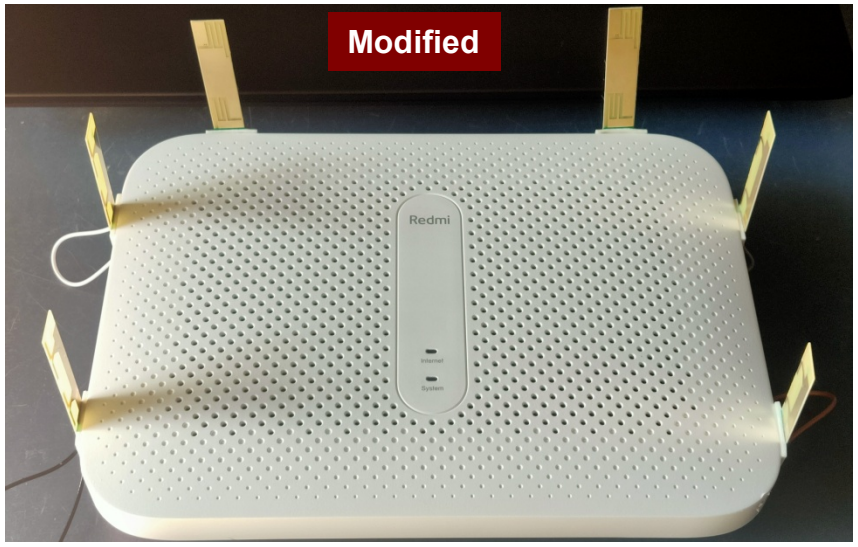
BHWR250 Wi-Fi Signal Strength Benchmark #1

Signal Strength & Throughput on Galaxy S10e with R7800 on TV Top in Living Room

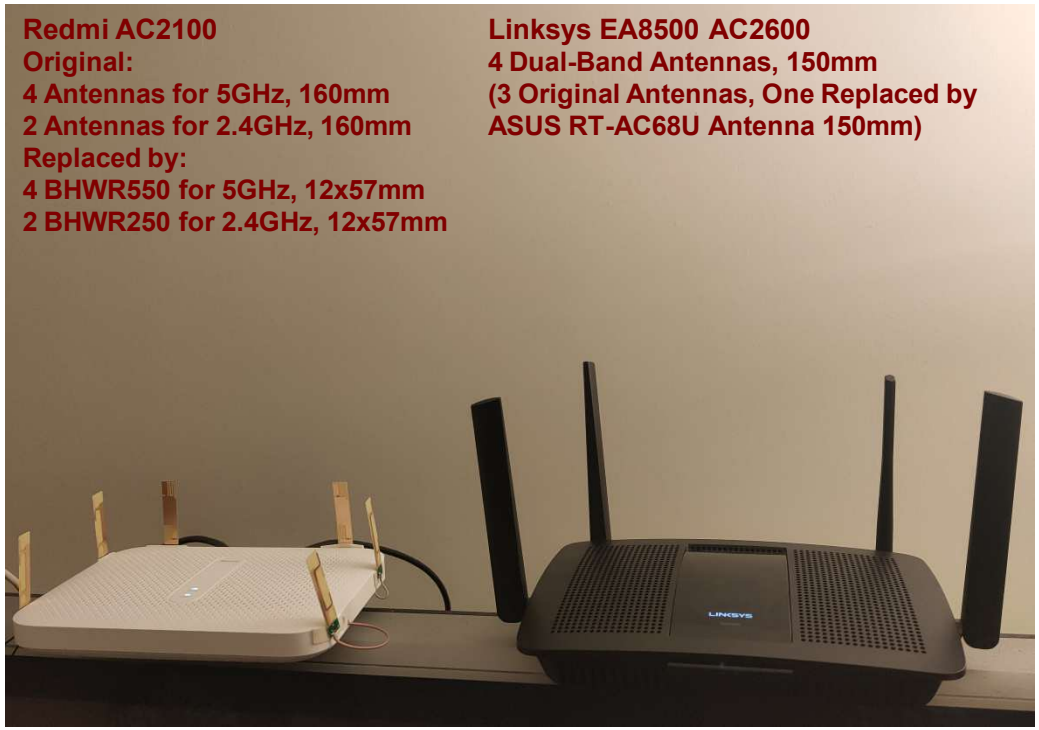
	Living Room	Bedroom	Kitchen	Lab
Original Antenna				
BHWR250				

BHWR250/550 Wi-Fi Signal Strength Benchmark #2

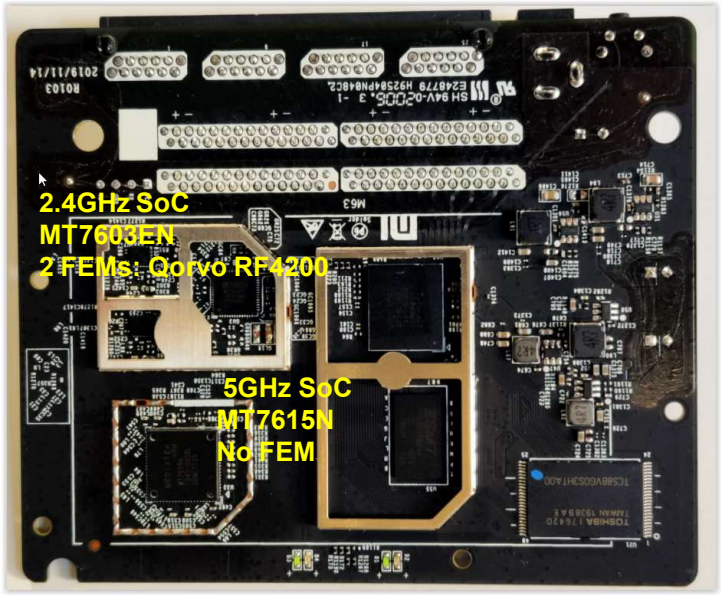
Replacing Antennas on Redmi AC2100 with BHWR250/BHWR550



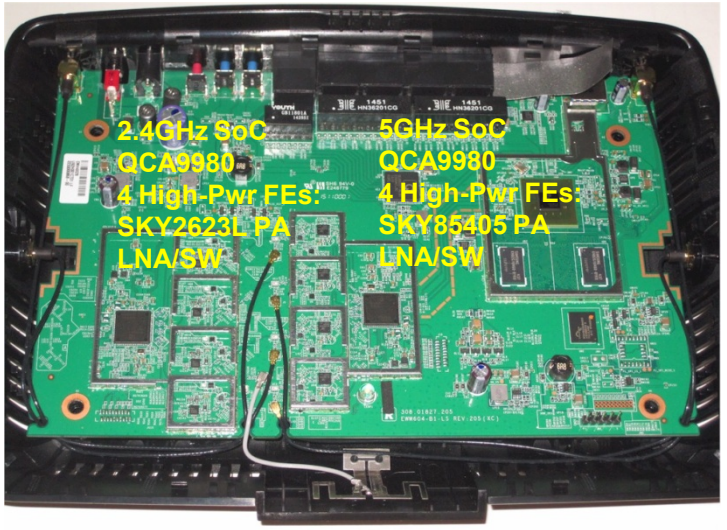
BHWR250/550 Wi-Fi Signal Strength Benchmark #2



Redmi AC2100 Main Board



Linksys EA8500 Main Board



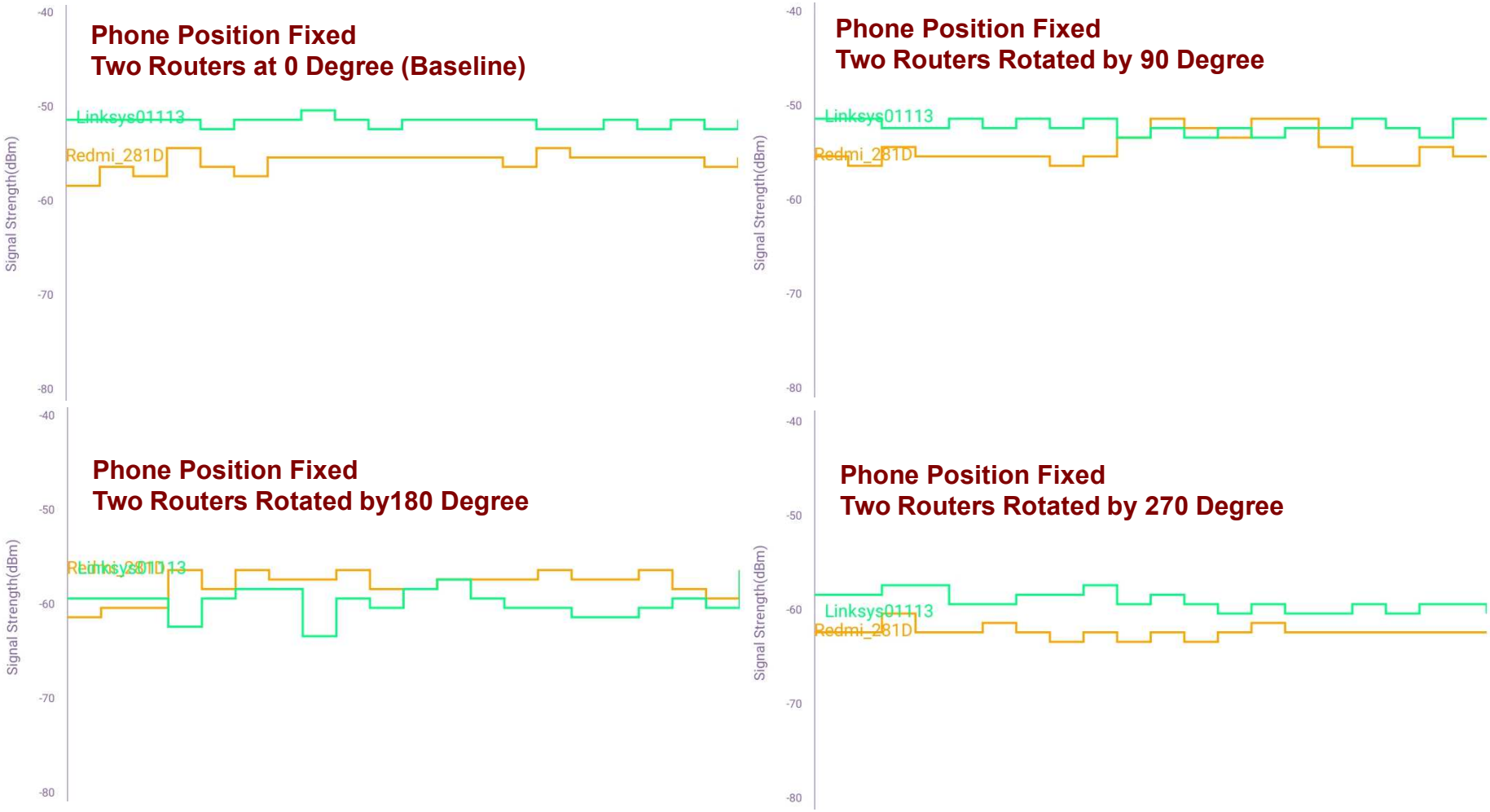
Notes:

- Redmi AC2100 retails for under $30 due to simple designs, while Linksys retails for around $175, as of Jan'2021.
- As shown in the following pages, both walk-through and fixed-location tests show comparable signal strengths (and corresponding Wi-Fi data rates) , after the Redmi AC2100 antennas are replaced with BHWR250/BHWR550. In fact, Redmi AC2100 shows higher receive signal strength in some test cases.

BHWR250/550 Wi-Fi Signal Strength Benchmark #2

Redmi AC2100 vs Linksys EA8500

2.4GHz Signal Strength Comparison with Wi-Fi Analytics on Samsung S7
Time Lapse of Signal Strength with Phone on Kitchen Table , 4 Orientation Angles for Routers



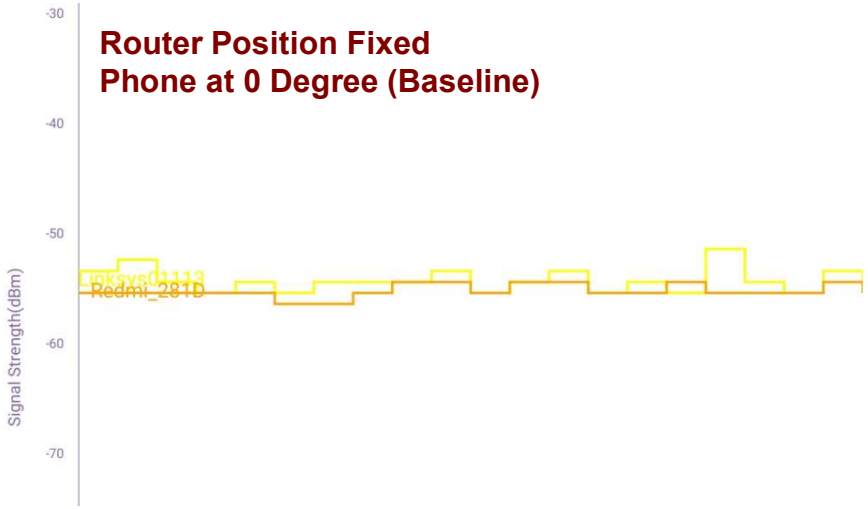
Note: Redmi AC2100 with two BHWR250 and two FEMs shows comparable or only slightly lower signal strength when compared to Linksys EA8500 which has 4 dual-band antennas and 8 high-power PA based RF FEs.

BHWR250/550 Wi-Fi Signal Strength Benchmark #2

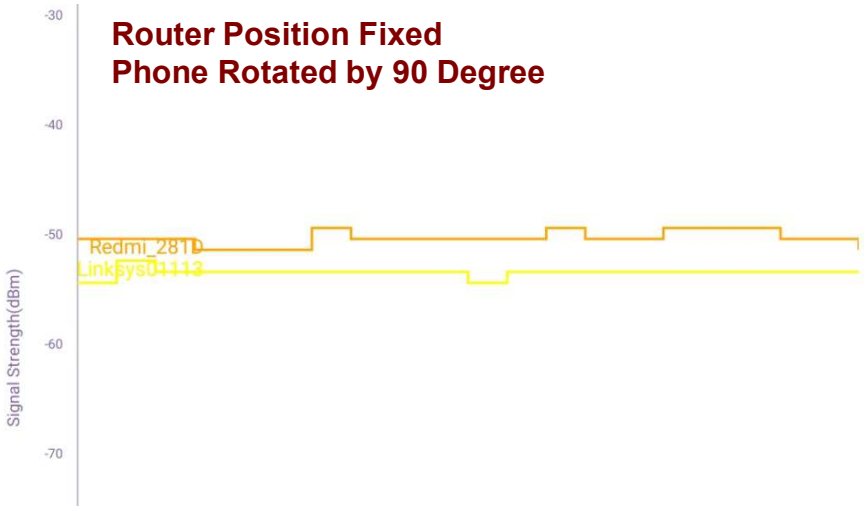
Redmi AC2100 vs Linksys EA8500

2.4GHz Signal Strength Comparison with Wi-Fi Analytics on Samsung S7
Time Lapse of Signal Strength with Phone on Kitchen Table , 4 Orientation Angles

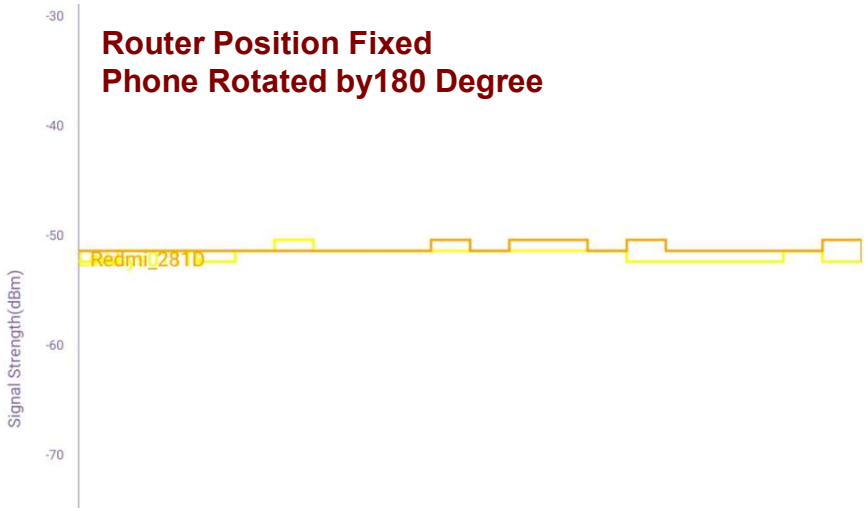
Router Position Fixed
Phone at 0 Degree (Baseline)



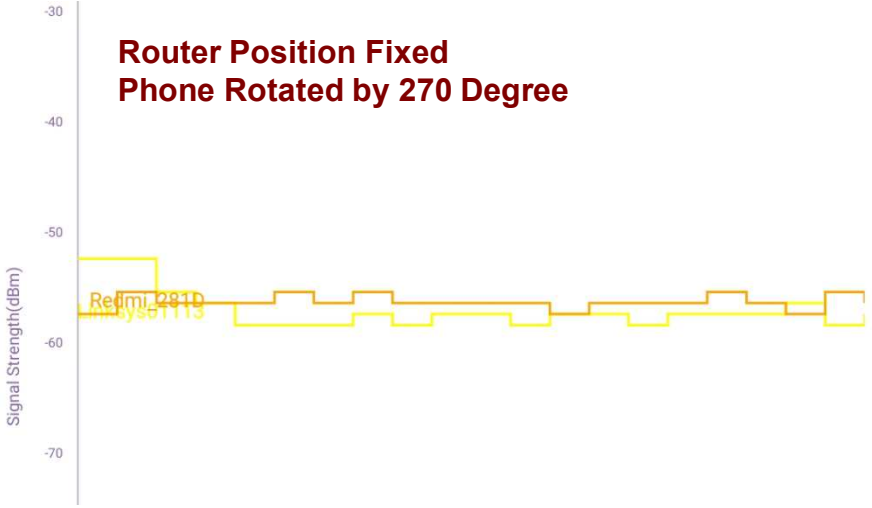
Router Position Fixed
Phone Rotated by 90 Degree



Router Position Fixed
Phone Rotated by180 Degree



Router Position Fixed
Phone Rotated by 270 Degree



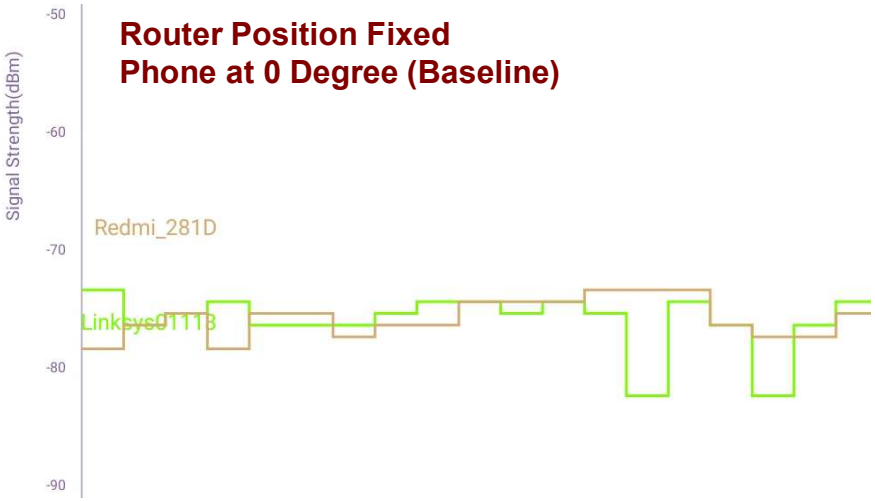
Note: Redmi AC2100 shows slightly higher overall signal strength even though it has only two BHWR250 2.4GHz antennas while Linksys EA8500 has 4 dual-band antennas.

BHWR250/550 Wi-Fi Signal Strength Benchmark #2

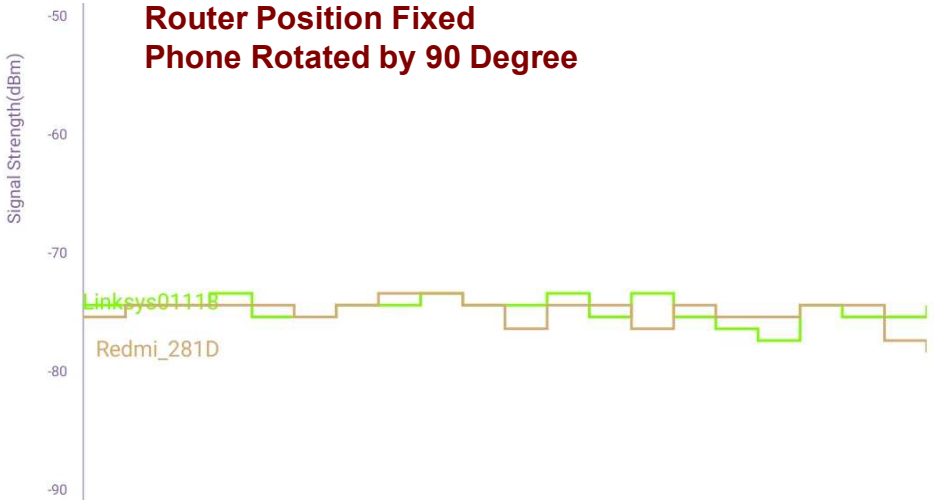
Redmi AC2100 vs Linksys EA8500

2.4GHz Signal Strength Comparison with Wi-Fi Analytics on Samsung S7
Time Lapse of Signal Strength with Phone in Backyard, 4 Orientation Angles

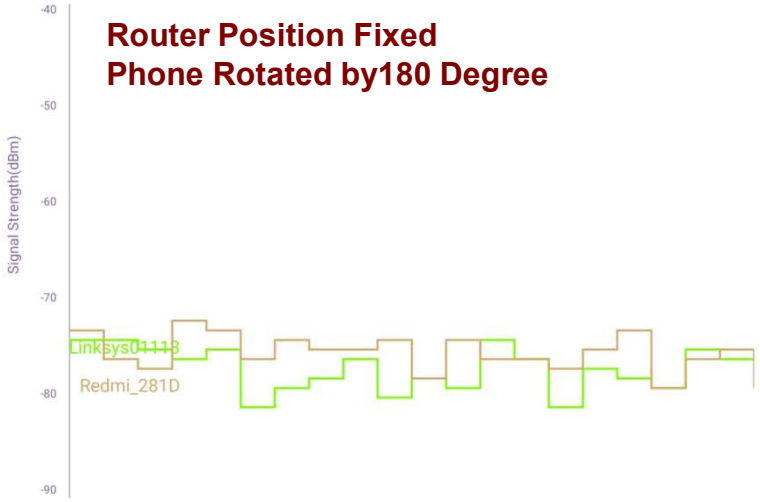
Router Position Fixed
Phone at 0 Degree (Baseline)



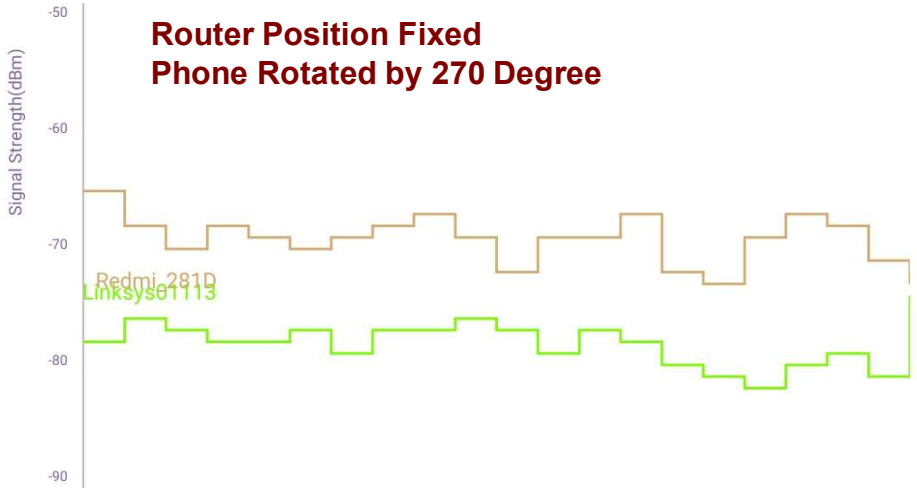
Router Position Fixed
Phone Rotated by 90 Degree



Router Position Fixed
Phone Rotated by180 Degree

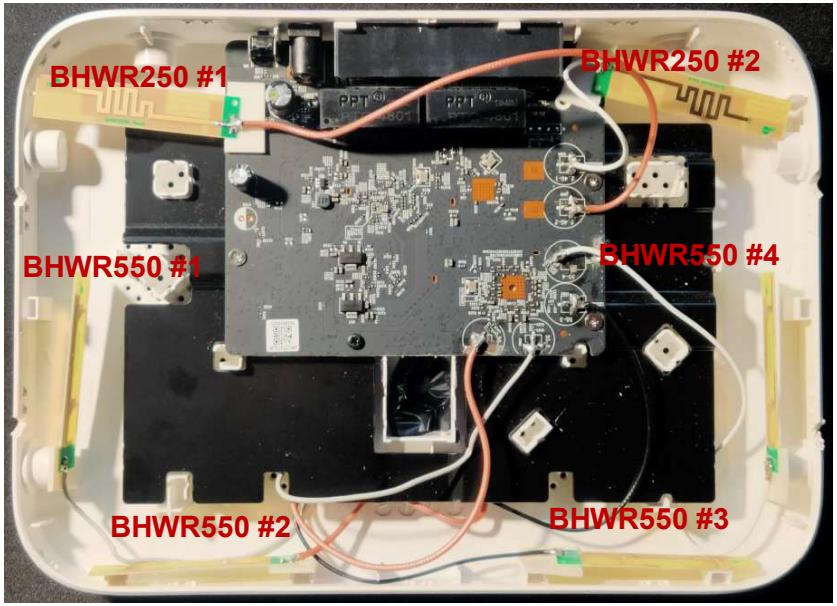


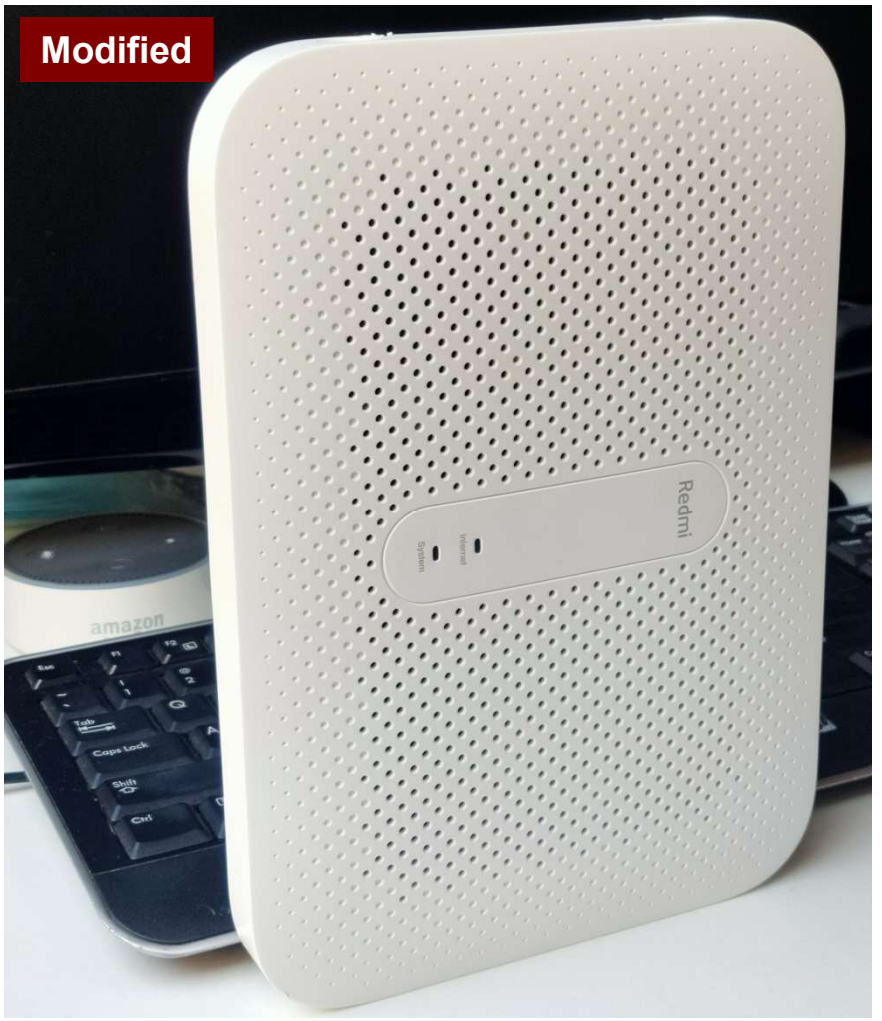
Router Position Fixed
Phone Rotated by 270 Degree



Note: Redmi AC2100 shows higher overall signal strength, especially for one orientation of the phone.

BHWR250 for Embedded Wi-Fi Router Antenna



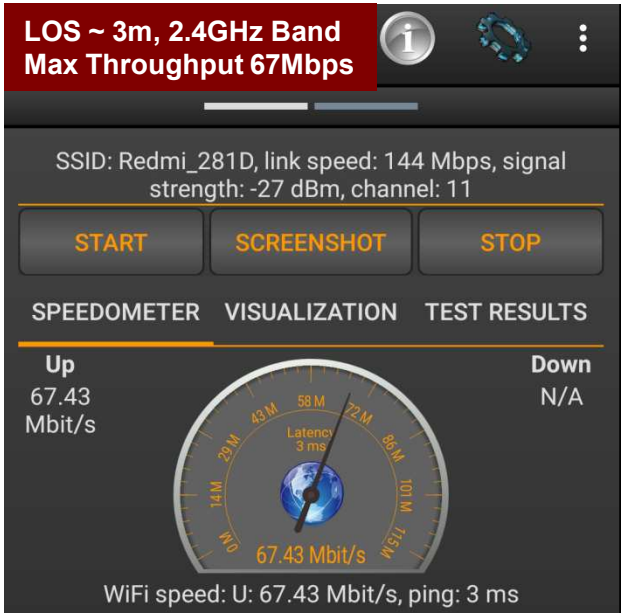


Note: This experiment is for feasibility study only. Actual implementation of these embedded antennas should be designed properly for specific product IDs.

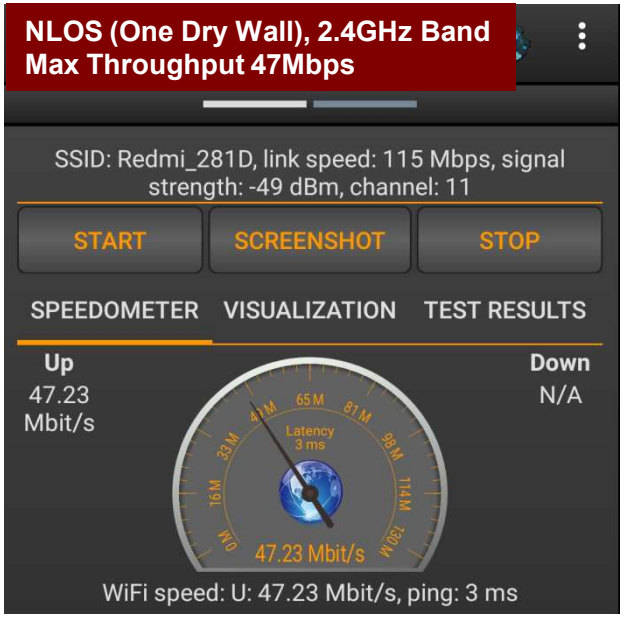
BHWR250 for Embedded Wi-Fi Router Antenna

Signal Strength & WiFi-to-LAN Throughput Test

LOS ~ 3m, 2.4GHz Band
Max Throughput 67Mbps



NLOS (One Dry Wall), 2.4GHz Band
Max Throughput 47Mbps



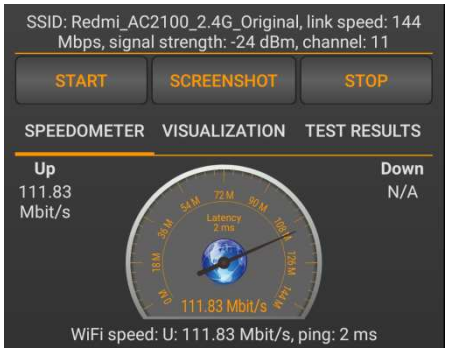
Notes:

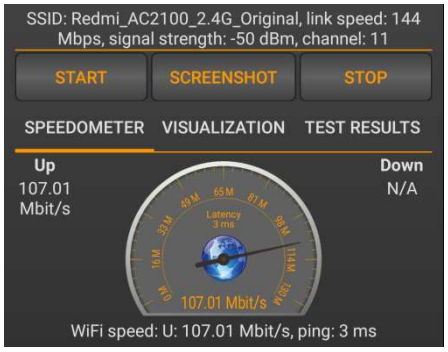
- **Redmi AC2100 dual-band router was modified by replacing six original antennas with BHWR250 (x2) and BHWR550 (x4)**
- **All six antennas were moved inside the router for improved aesthetics, as well as manufacturing cost reduction**
- **The modified router with embedded antennas was connected to a laptop with Ethernet cable to be used as TCP server for WiFi-to-LAN throughput test.**
- **WiFi Speed Test Pro (Android APP) on Samsung Galaxy S10e was used to test WiFi speed at various locations.**

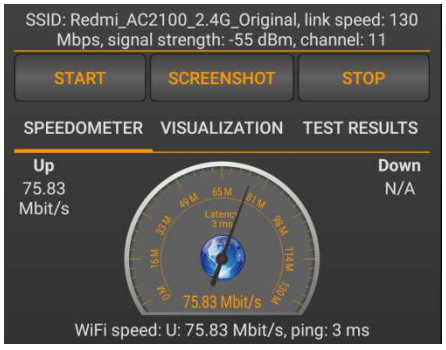
BHWR250 for Embedded Antenna: Benchmark Test

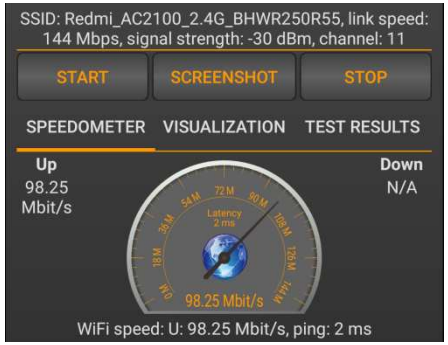
Signal Strength & WiFi-to-LAN Throughput Test

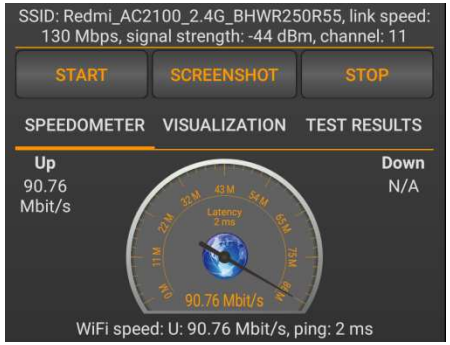
Site 1 LOS ~3m	Site 2 NLOS (1 Wall)	Site 3 NLOS (2 Walls)

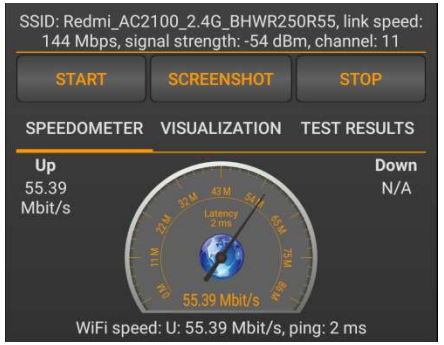








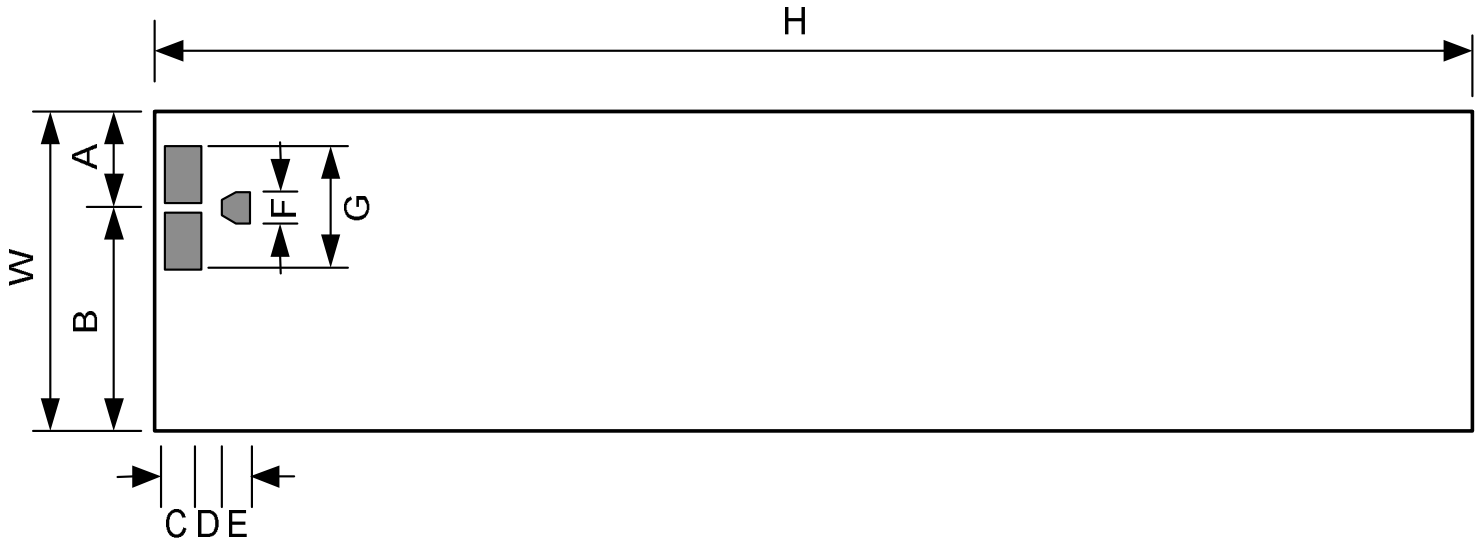




Notes:

- **Redmi AC2100 dual-band router Unit #2 was modified by replacing six original antennas with BHWR250 (x2) and BHWR550 (x4).**
- **All six antennas were moved inside the router for improved aesthetics, as well as manufacturing cost reduction.**
- **The two router units were placed at the same location and connected to a laptop with Ethernet cable to be used as TCP server for WiFi-to-LAN throughput test.**
- **WiFi Speed Test Pro (Android APP) on Samsung Galaxy S10e was used to test WiFi speed at various locations.**
- **This benchmark test is for feasibility study only. The test results are preliminary due to non-ideal positioning of embedded antennas inside the router case. Expect slightly improved performance after antenna positioning is optimized for new ID design.**

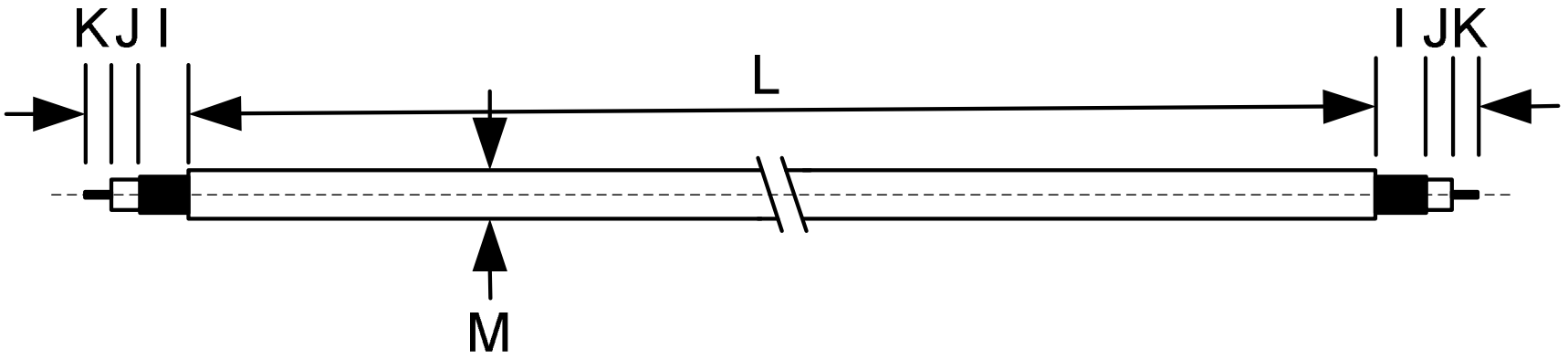
BHWR250 Mechanical Specifications



Symbol	Min. (mm)	Typ. (mm)	Max. (mm)
A	3.5	3.6	3.7
B	8.3	8.4	8.5
C	1.4	1.5	1.6
D	0.7	0.8	0.9
E	1.3	1.4	1.5
F	1.2	1.3	1.4
G	4.5	4.6	4.7
H	56.9	57	57.1
W	11.9	12	12.1

Note: Dark grey area is solder mask opening for IPX/UFL cable assembly.

BHWR250 IPX/UFL Cabling Recommendation



Symbol	Min. (mm)	Typ. (mm)	Max. (mm)
I	1.9	2.0	2.1
J	0.9	1.0	1.1
K	0.7	0.8	0.9
L		See Note*	
M		1.37	

Notes:

- **To minimize insertion loss and VSWR degradation, please use IPX/UFL cable with well-controlled 50-Ohm impedance and shortest cable length allowed for each product design.**
- **To best preserve 50-Ohm impedance, minimize VSWR degradation and saving cost, it is recommended that the IPX/UFL cable for BHWR250 is soldered directly to the main PCB, instead of using connectors.**
- **For cost-sensitive 2.45GHz band applications, IPX/UFL cables with 1.13mm diameter can be used alternatively without major impact on VSWR and insertion loss.**

BHW RF Front-End Solutions AppNote Library

In addition to standard datasheets and EVB/BOM info, BHW publishes an AppNote series that address various topics on RF front-end design and performance over a wide frequency range from 300MHz to 6GHz, as an effort to assist customers in developing cutting-edge, cost-competitive products:

- BHW AppNote #001 - Cross-Over Cascade of BHWM253 to Boost Tx Power and Rx Sensitivity of 2.4GHz Systems
- BHW AppNote #002 - Accurate Benchmark of GNSS CN0 Using the Power-Splitter Method
- BHW AppNote #003 - Boosting Wi-Fi Tx Power and Rx Sensitivity with BHWA251 and BHWM252
- BHW AppNote #004 - UHF 900MHz RF Front-End Solution Using BHWA251 Half-Watt PA and BHWL160 Sub-1dB-NF LNA
- BHW AppNote #005 - Sub-1GHz Applications of BHWA350 2-in-1 Wideband Fully Matched Amplifier
- BHW AppNote #006 - Low-Noise High-IIP3 LNB Architecture for Dual-Band High-Precision GNSS Using Cascade of BHWL160
- BHW AppNote #007 - UWB RF Front-End Solution Using BHWA350 and BHWM552
- BHW AppNote #008 - High-Power 5.8GHz RF Front-End Solution Using BHWA555 and BHWM552 for ETC, V2X and Wireless Video
- BHW AppNote #009 - 5.8GHz RF Front-End Using BHWA350 and BHWM552 for Wireless Audio
- BHW AppNote #010 - Multi-Constellation GNSS Active Antenna Using BHWL161 Cascade and Single-Fed Dual-Band Antenna
- BHW AppNote #011 - BHWL161 Super-Compact Low-Power Low Noise Amplifier for Range Extension of 2.4GHz RC and IoT
- BHW AppNote #012 - Enabling Cost-Effective High-Precision GNSS Using BHWL161 and Linear-Polarization PCB Antenna
- BHW AppNote #013 - GNSS Noise Floor vs Receiver Architecture
- BHW AppNote #014 - Designing Ultra Low-Power High-Performance GNSS Products Using BHWL160 GaAs PHEMT LNA
- BHW AppNote #015 - BHWL161 GNSS Full-Band High-Performance LNA in Super-Compact 1x1mm DFN with Relaxed Pin Pitch
- BHW AppNote #016 - Improving GNSS NF Measurement Accuracy Using Broadband LNA BHWL161 as Pre-Amp
- BHW AppNote #017 - High-Efficiency, Low-NF 2.4GHz Front-End Solution for IoT Using BHWA251 and BHWM252
- BHW AppNote #018 - Optimizing BHWA555 Wideband One-Watt PA for Long-Range 5.8GHz Transmitter Applications
- BHW AppNote #019 - Miniature 2.4GHz RF Front-End with Integrated Chip Antenna and BHWM253 for TWS and IoT
- BHW AppNote #020 - Multiplying the Range for 2.4GHz Music Streaming with BHWR250L Active Integrated Antenna (AiA)
- BHW AppNote #021 - Range Extension for 2.4GHz Wireless Systems with BHWR250M Active Integrated Antenna (AiA)
- BHW AppNote #022 - Enabling Long-Range Angle-of-Arrival for High-Precision Indoor Positioning with BHWR250N RF AiA
- BHW AppNote #023 - Extend the Range for 5.8GHz Audio/Video Streaming with BHWR580M Active Integrated Antenna (AiA)
- BHW AppNote #024 - Improving 5.8GHz Radio Link Budget with BHWR580L Active Integrated Antenna (AiA)
- BHW AppNote #025 - Improving Range and Throughput of 2.4GHz Wi-Fi with BHWR250 Dual-Slot Quasi-Diversity Antenna
- BHW AppNote #026 - Improving Range and Throughput of 5GHz Wi-Fi with BHWR550 Array Antenna
- BHW AppNote #027 - Coin-Cell and Batteryless 1km Long Range NanoBeacon with BHWR250A AiA and Energy Harvesting
- BHW AppNote #028 - Use BHWM252 Cascade to Extend Range of 2.4GHz Wireless Systems with Single-Port SoCs
- BHW AppNote #029 - Improving Range of 2.4GHz Wireless Microphones and Audio Systems with BHWR250A Active Integrated Antenna (AiA)
- BHW AppNote #030 - Simultaneous Improvement in Range and Battery Life of 2.4GHz Wireless Systems with BHWR250M AiA

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