Assessment of Deployable Systems Operational Power Consumption and Endurance

First Responders Group

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Table of Contents

List of Figures

List of Tables

1 Overview

The Public Safety Communications Research (PSCR) program has been evaluating different types of public safety broadband deployable systems (DS) to provide an assessment of the state of the industry to the Office of Interoperability and Compatibility of the Department of Homeland Security (DHS). This report covers the assessment of operational power consumption and endurance, which was extended into FY2017, and replaces the interim report, which was issued in FY2016.

To achieve the DS project goals, PSCR acquired several DS types for the evaluation effort. The cell-on-wheels (COW) and the man-pack portable systems were chosen for initial evaluation. Other DS types, such as the system-on-wheels (SOW) and airborne systems, may be considered for future testing. Many of these systems can operate in stand-alone mode (i.e., a network within itself) or with backhaul infrastructure, including microwave or satellite links. The COW DS is representative of an industry 4G Long-Term-Evolution (LTE) macro Evolved Node B (eNodeB) implementation. The man-pack DS is a small and portable system, relative to a COW DS.

One of the key limitations of a DS is its operational endurance, which is constrained by the capacity of a portable power source and system power requirements. With respect to the power requirements, the operational states of a DS can be categorized in three scenarios: 1) deployment, 2) unloaded steady state and 3) fully loaded operation. Utilizing COW and man-pack DS's and supporting networks currently available at PSCR, a power analysis of the two DS types in these three scenarios was conducted. The objective of this assessment was to identify the power measurements that should be made to determine the operational endurance of a particular DS.

2 Power Configuration

The power system of a DS may be comprised of a number of essential components (generation and consumption) as described below.

- **COW DS:** COW DS are more commonly available from the industry today in comparison with other types of DS. Cellular providers regularly use COWs to provide temporary network access, and some Band 14 COW DS are currently operating in the field in early builder public safety networks. The COW DS components typically are installed on a vehicle trailer and are towed to the desired deployment location. In addition to the main components of a LTE network, including the eNodeB(s), system module, network equipment, antennas and antenna mast, the trailer also hosts an AC power generator, an HVAC unit

for environment control, AC to DC rectifiers and power distribution units. The diagram in Figure 1 below shows a top-level power configuration of the COW DS under test. AC power is generated by a gasoline-fueled 240 VAC power generator and distributed to 120 VAC and 240 VAC circuit breakers. The rectifier converts a 120/240 VAC input source to -54 VDC, which is commonly used by industrial LTE eNodeB(s). The eNodeB has three cells for full 360-degree coverage, and each cell uses two transmitting/receiving (TX/RX) antennas for multiple-input-multiple-output (2x2 MIMO) operation. Each TX port is capable of transmitting up to 46 dBm of radio frequency (RF) power. Other major components of a COW, as shown in the diagram, use the power from the 120 VAC source.

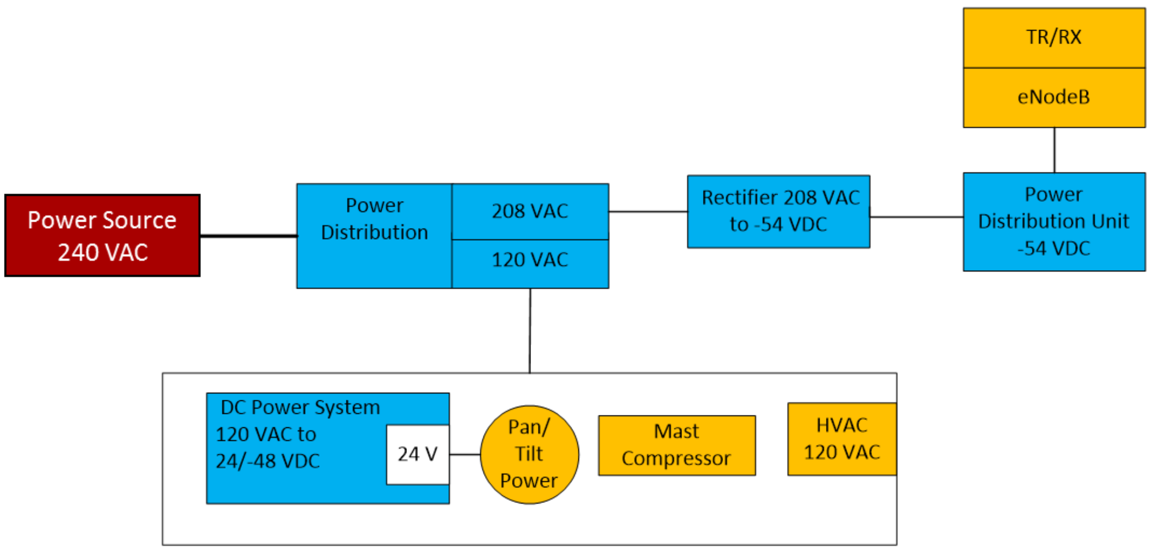

Figure 1 - Major Power Components of the COW DS Under Test

- **Man-Pack Portable DS:** The man-pack portable DS operates as a stand-alone, network-in-a-box system. As depicted in Figure 2, two basic physical components comprise the man-pack DS – the LTE unit and the battery unit. The LTE unit consists of a relatively low-power eNodeB capable of 30 dBm output per TX port, and the Evolved Packet Core. There are two TX ports for MIMO operation. The DS can operate using either DC or AC power sources; AC power is converted to DC by an internal AC to DC converter. The battery unit provides DC power to the LTE unit when there is no AC power source, and it charges when AC power is connected to the system. The combined mass of the two units is 20.45 kg (45 lbs.), with the majority of the mass in the LTE unit.

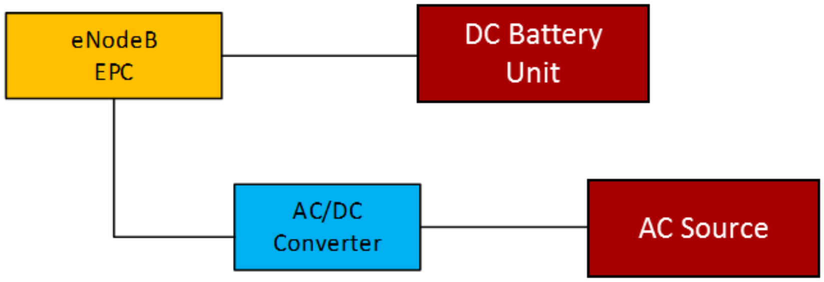

Figure 2 - Major Power Components of the Man-Pack Portable DS Under Test

3 Power Assessment

The power assessment of the DS under test was conducted in two phases:

1. Phase I: Identifying components that provide or consume the majority of the power and locations at which power meters should be installed for power measurements; and
2. Phase II: Measuring power parameters of those components identified in Phase I.

3.1 Phase I - Evaluation Results

Preliminary tests determined which components consumed the majority of the generated power. The tests were performed in unloaded steady state (RF power was on but with no active data session) and in fully loaded operation (maximum RF power transmission and 100 percent fully loaded traffic). The approach for forcing the DS in fully loaded operation to generate and consume maximum power was to set the eNodeB to transmit at maximum RF power per port and other DS components to operate at their maximum operation capacity. In either test scenario, the AC generator's fuel tank started at full capacity. Ratings of the components are listed below in reference to Figure 1.

- **COW DS Test Configurations**
  - Power Generator
    - Rated output: 5500 VA
    - 120/240 VAC Single Phase
    - Effective fuel tank capacity: 4.5 gallons
  - eNodeB
    - COW
    - Three cells, two TX/RX antenna ports per cell
    - Maximum output power at TX port: 46 dBm

- HVAC
  - 115 VAC
  - Rated current (max): 10.9 A
- Pan/Tilt Power Unit
  - 24 VDC
- Mast Compressor
  - 115 VAC

3.1.1 COW DS in Unloaded Steady State

The eNodeB was configured for unloaded steady state, with no active user traffic data sessions. TX power levels were maintained at an average of 36 dBm throughout the test. The TX ports' power levels and eNodeB alarms were monitored via the vendor's graphical user interface (GUI) application throughout the test. Other components of the COW DS also operated until the test concluded. The eNodeB consumed the greatest part of the generated power, followed by the HVAC. Preliminary results for the COW under test showed that the power consumption ratio between the eNodeB and the HVAC was 1.75 to 1, respectively. The test lasted for seven hours, concluding when the AC generator's fuel tank emptied.

3.1.2 COW DS in Fully Loaded Operation

The eNodeB was set in local test mode to transmit at 100 percent fully loaded configuration. Each of the six TX ports of the eNodeB transmitted continuously at maximum power of 46 dBm (in MIMO configuration). Other components of the COW DS also operated until the test concluded. The TX ports' power levels and the eNodeB alarms were monitored via the vendor's GUI application throughout the test. System reports confirmed that TX power levels were maintained at an average of 46 dBm throughout the test. As in the unloaded steady state case, the eNodeB consumed the greatest part of the generated power, followed by the HVAC. Preliminary results for the COW under test showed that the power consumption ratio between the eNodeB and the HVAC was 3 to 1, respectively. The test concluded after four hours when the AC generator's fuel depleted.

3.1.3 Man-Pack Portable DS Test Configuration

During Phase I testing, there was no direct method for monitoring the power consumption of the LTE unit. To ensure delivery of required power from the battery unit to the LTE unit, TX RF power levels were measured, and the throughput rate of the data session was monitored via the vendor's mobile device GUI application. The battery unit was drained before testing and charged overnight to ensure that it was fully charged before testing began.

The man-pack portable DS has two TX/RX antenna ports, with each port capable of transmitting up to 39 dBm. The unit was configured for MIMO mode. Since the

man-pack portable DS is simplistic in its user interface and operation, the unit may be set for power-off, stand-by mode (the unit is powered on but not on-air) or transmitting mode by changing the position of a toggle switch.

3.1.4 Man-Pack Portable DS in Unloaded Steady State

The DS was set in unloaded steady state with no active user data session. Average RF power was measured at 30 dBm per TX port. The test lasted for seven hours, concluding when the battery unit was depleted and RF transmission stopped.

3.1.5 Man-Pack Portable DS in Fully Loaded Operation

The DS was set in data session mode with uplink and downlink User Datagram Protocol sessions running continuously from a mobile device. The RF power level was rated by the manufacturer at 39 dBm per TX port, and the throughput rate at the mobile device remained stable throughout the test. The test concluded after five hours when the battery unit was depleted and RF transmission stopped.

3.2 Phase II - Power Measurement Approach

During phase II, the power measurement approach set up the test configuration and position of power meters in locations that measured power generation/consumption values in each of the three scenarios. Using these measurements, we were able to determine operational endurance in relation to power generation and consumption of the DS, which may be used to specify energy/fuel requirements for a field scenario.

3.2.1 COW DS Deployment

For the deployment scenario, the pan/tilt unit, HVAC and mast compressor were activated individually, and power measurements were taken with meters positioned, as shown in Figure 3.

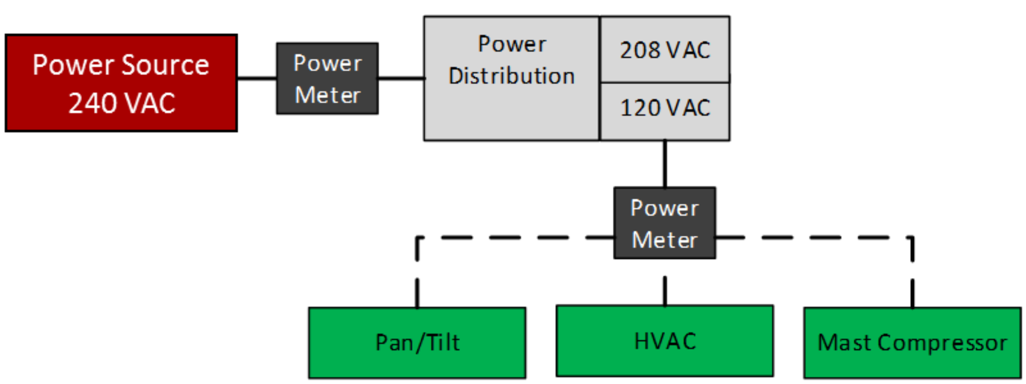

Figure 3 - COW DS Deployment Power Measurement Test Set Up

3.2.2 COW DS Unloaded Steady State

In the unloaded steady state, power measurements were recorded at the AC power generator, the eNodeB and the HVAC, as shown in Figure 4. The eNodeB was powered on with no data session. The eNodeB TX transmitting power remained at its low level, translating to minimum power consumption by the eNodeB. The HVAC was operating to provide controlled environmental conditions to components as needed.

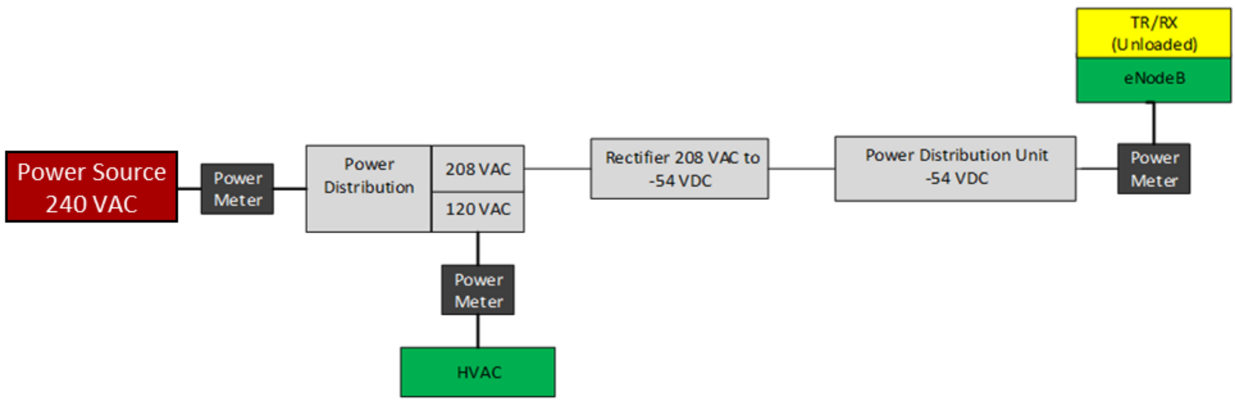

Figure 4 - COW DS Unloaded Steady State Power Measurement Test Set Up

3.2.3 COW DS Fully Loaded Operation

As in Phase I, the eNodeB was configured in local test mode for fully loaded traffic and transmitting at maximum RF power level. The HVAC was in operation, as in the unloaded steady state case. Power meters were positioned, as shown in Figure 5, to measure generated and consumed power. This scenario was expected to provide information for the maximum power generation and consumption of the COW DS.

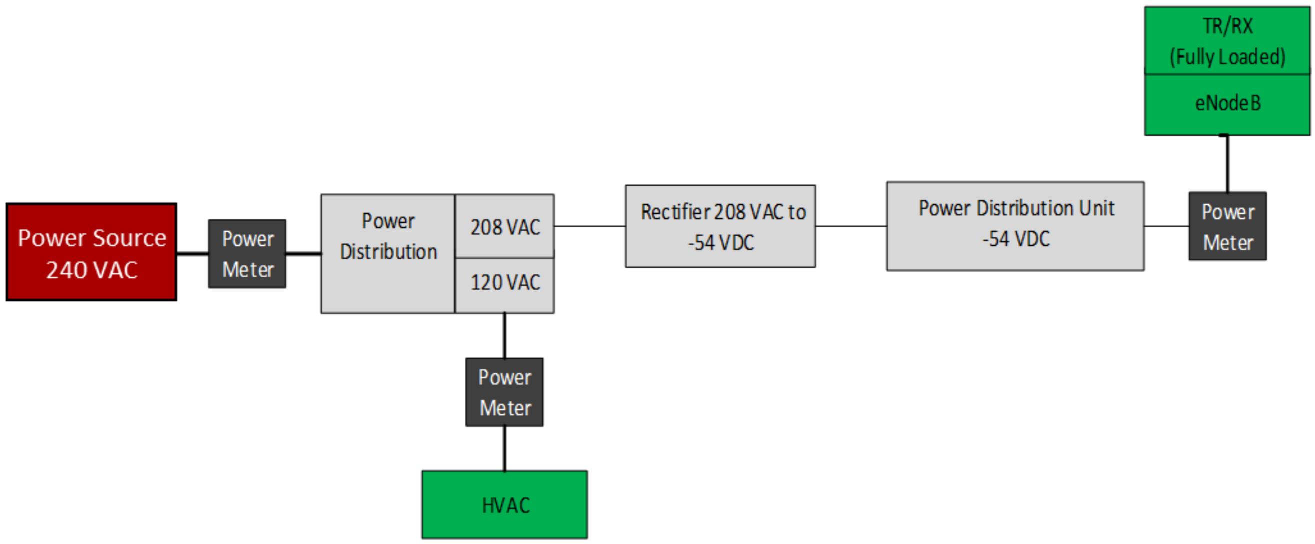

Figure 5 - COW DS Fully Loaded Operation Power Measurement Test Set Up

3.2.4 Man-Pack Portable DS – Standby, Unloaded Steady State and Fully Loaded Operation

For the man-pack portable DS, as shown in Figure 6, a power meter in conjunction with a break-out box was installed at the cable between the battery unit and the LTE unit to record power consumption when the DS was in operation. The unit was tested in: 1) stand-by mode (equivalent to deployment scenario) where the unit was powered on but with no RF transmission; 2) unloaded steady state; and 3) fully loaded operation as described in Phase I. Power measurements between the battery unit and LTE system provided information for power consumption relative to RF power transmission.

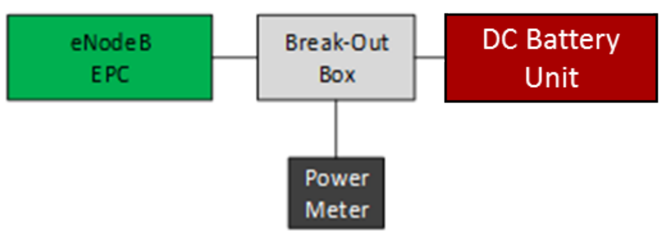

Figure 6 - Man-Pack DS Under Test Power Measurement Set Up

3.3 Phase II – Power Measurement Results

3.3.1 Purpose

As previously stated, the purpose of the power consumption analysis effort was to evaluate the power utilization during various states of operation in a typical DS. The first three tests focused on the PSCR COW in the following three conditions:

- Deployment;
- Operation in a steady, unloaded state; and
- Operation in a steady, fully loaded state.

The final tests focused on a man-portable deployable system under the following conditions:

- Operation in a steady, unloaded state, and
- Operation in a steady, fully loaded state.

Note that the deployment test and most of the COW measurements were not applicable for the man-portable system due to inherent differences in design. The testing strategy for the man-portable system is explained in Section 3.3.5.

The goal of the Phase II power measurement tests was to develop an initial power consumption profile using two types of deployable systems. Measurements were conducted using specific equipment, and the figures herein are representative only for those systems. It should be noted, however, that these systems were selected from available products based on their market readiness and respective manufacturers' industry engagement, in an effort to obtain and report typical indications for equipment to be employed in DS solutions.

3.3.2 Test Equipment (COW)

The following tools were used for the collection of the data:

- Extech Instruments 380803 AC Power Analyzer (x2)
  - Accuracy: ± 0.5% of voltage and current reading
  - Calibration traceable to NIST
- West Mountain Radio PWRCheck DC Power Analyzer
  - Accuracy: ± 10 mV, ± 10 mA

Method and Reference Points

The test methods and applicable measurement/reference points are detailed in each individual test case. A full diagram of all test points utilized can be found in Appendix A.

3.3.3 COW Measurements

For the first part of the Phase II DS Power tests, the PSCR COW was utilized as it is representative of macro-cell based COW DS commonly deployed. It should be noted that the measurements collected from this test are assumed to be representative of similar systems. Actual performance may vary between individual manufacturers' devices utilizing different architectures or components.

3.3.3.1 Test 1 – COW Setup and Deployment

The purpose of the first test was to assess the power consumption of the COW during normal deployment operations. For the purposes of this experiment, the deployment process consisted of raising the antenna mast and using the pan-tilt-zoom system to align a microwave antenna. No other power systems were utilized during the deployment phase.

Figure 7 below shows the configuration for this test. As the mast compressor was the only system under test, the AC analyzer was connected to the compressor.

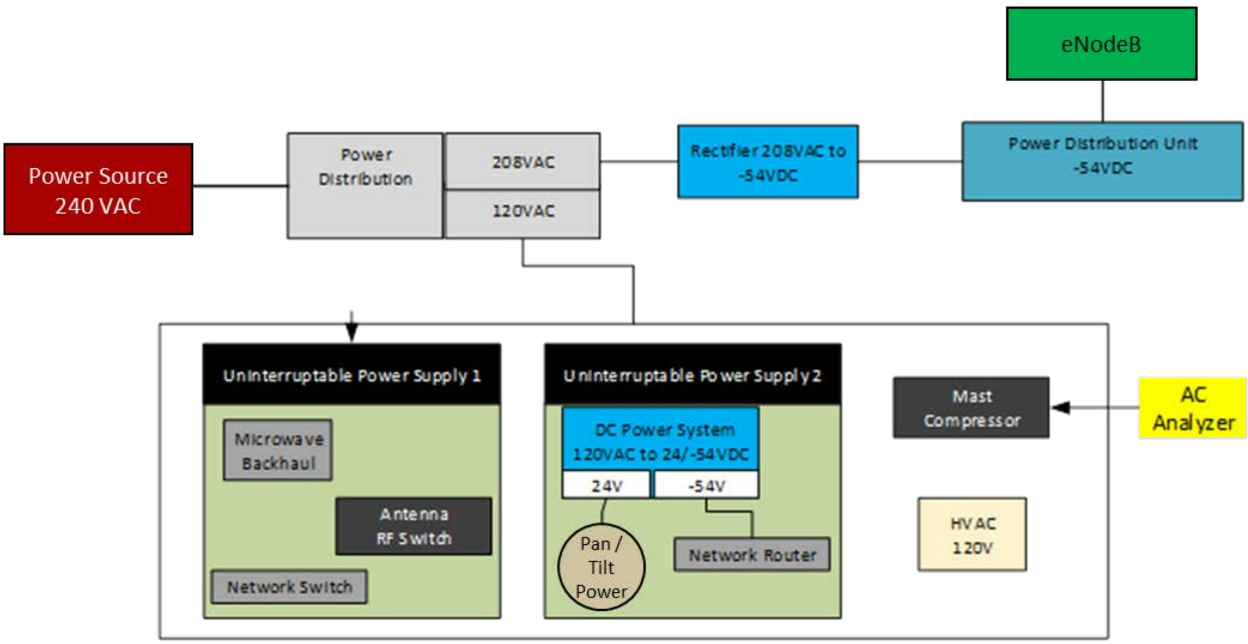

Figure 7 - Test 1 Configuration

To execute the test, the compressor was enabled and the mast was raised. The mast on the COW used for this test, which is representative of a majority of large deployable systems, can be raised in multiple segments for any desired height between 12 feet and 46 feet. For this test, three segments were raised to a height of 28 feet. It should be noted that the compressor only operates when the mast is being raised. When the mast is not in operation, the compressor draws no power. Results are presented below in Figure 8. The mast extension operation ran from approximately 08:00 minutes to 11:00 minutes during the data collection period.

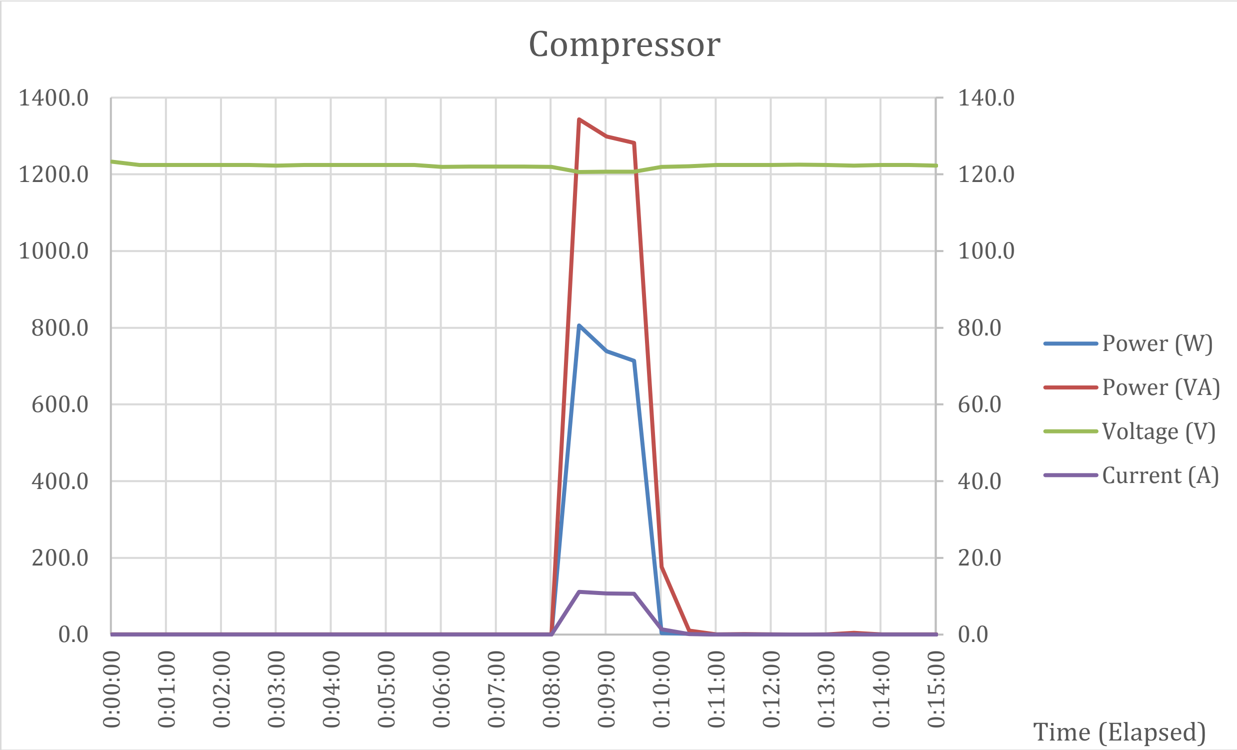

Figure 8 - Test 1 Deployment

As the primary source of power draw during deployment, the compressor was the main point of measurement. Table 3 below details the total power draw of all components. The measurement reference point for this test is reference point 4 (see Figure 18).

3.3.3.2 Test 2 – COW Operations in a Stable, Unloaded State

The purpose of this test was to measure and evaluate the power consumed by the COW when the system was fully powered up, but in an unloaded state. That is to say, all systems were functional, including the microwave backhaul link. The eNodeB was powered up, as were all other appliances and devices. However, there were no User Equipment (UE) devices connected to the eNodeB. In this state, the eNodeB only transmits non-Physical Downlink Shared Channel Resource Elements (RE). Therefore, the average power transmitted by the eNodeB is about 36 dBm. For reference, at a maximum traffic (or fully loaded) state, the average power approaches 46 dBm.

For this test, a DC analyzer was placed at reference point 1 (between the DC rectifier and the DC Protocol Data Unit), an AC analyzer placed at reference point 2 (between the 240VAC generator and the AC PDU), and a second AC analyzer placed at reference point 3 (on the 120VAC HVAC unit). The configuration is depicted below in Figure 9.

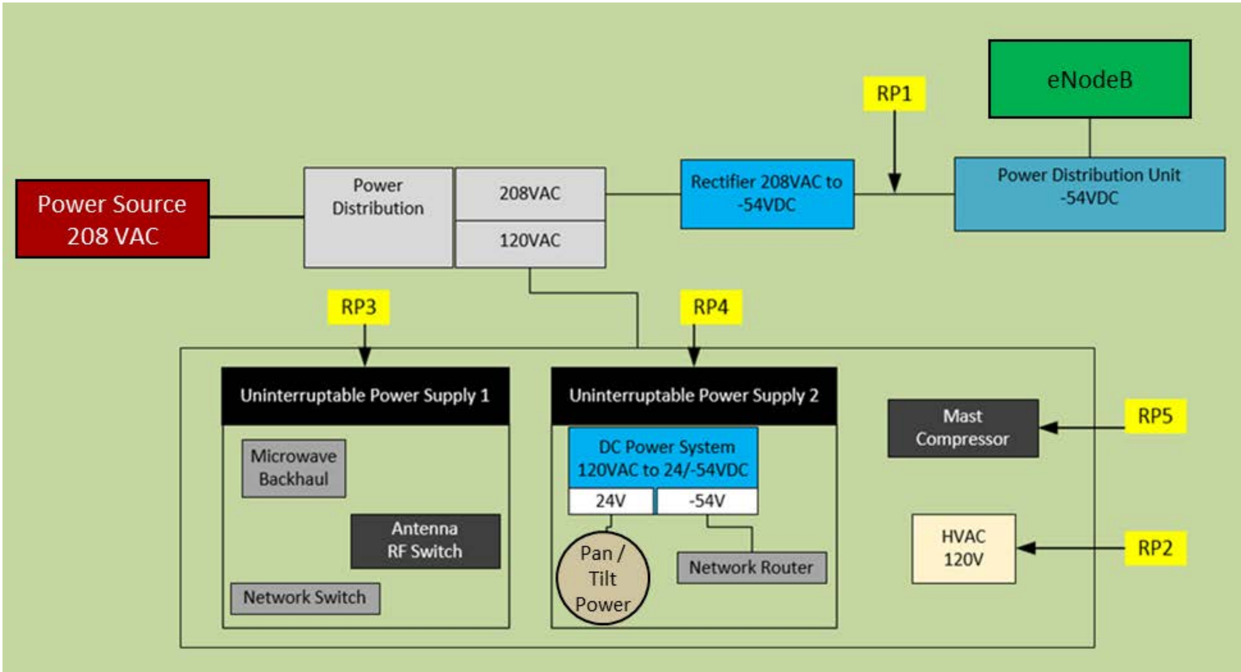

Figure 9 - Test 2 Configuration

Figure 10 below graphically depicts the power consumption measured at the various analyzers during this test.

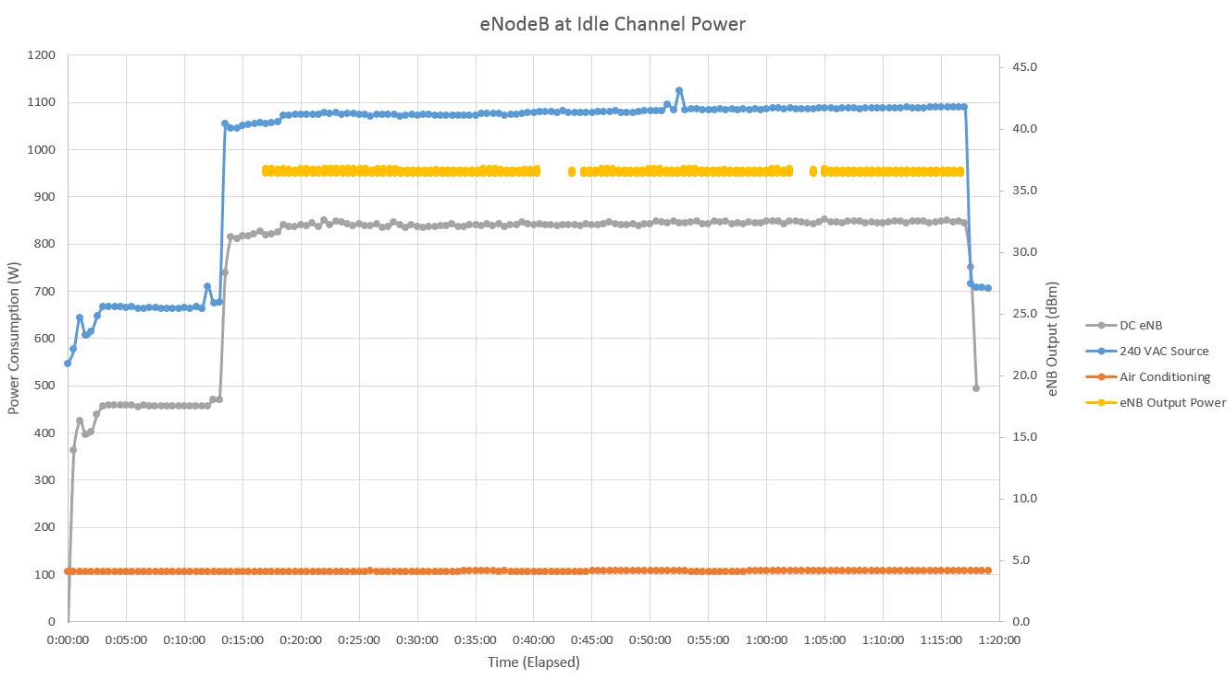

Figure 10 - Test 2: Stable, Unloaded

The eNodeB at idle channel power consumed approximately 850 W, while the overall consumption seen at the main 208 VAC lines was slightly less than 1100 W. Prior to unlocking the eNodeB, its consumption was approximately 475 W. Also, it should be noted that the air conditioning system remained at its minimum consumption throughout the test. This was due to the condenser and pump not engaging, as the outside air temperature was between 35ºF and 40ºF. Additionally, the output power of the eNodeB remained at approximately 36 dBm throughout the test.

3.3.3.3 Test 3 – COW Operations in a Stable, Fully Loaded State

The purpose of this test was to measure and evaluate the power consumption of the COW with the system fully powered up and in a fully loaded state. That is to say, all systems were functional, including the microwave backhaul link. The eNodeB was powered up, as were all other appliances and devices, and UEs connected to the eNodeB caused maximum downlink traffic levels on the network. Therefore, the average power transmitted by the eNodeB approached 46 dBm.

As in the previous test, a DC analyzer was placed at reference point 1 (between the DC rectifier and the DC PDU), an AC analyzer at reference point 2 (between the 240VAC generator and the AC PDU), and a second AC analyzer at reference point 3 (on the 120VAC HVAC unit). Figure 11 depicts the configuration below.

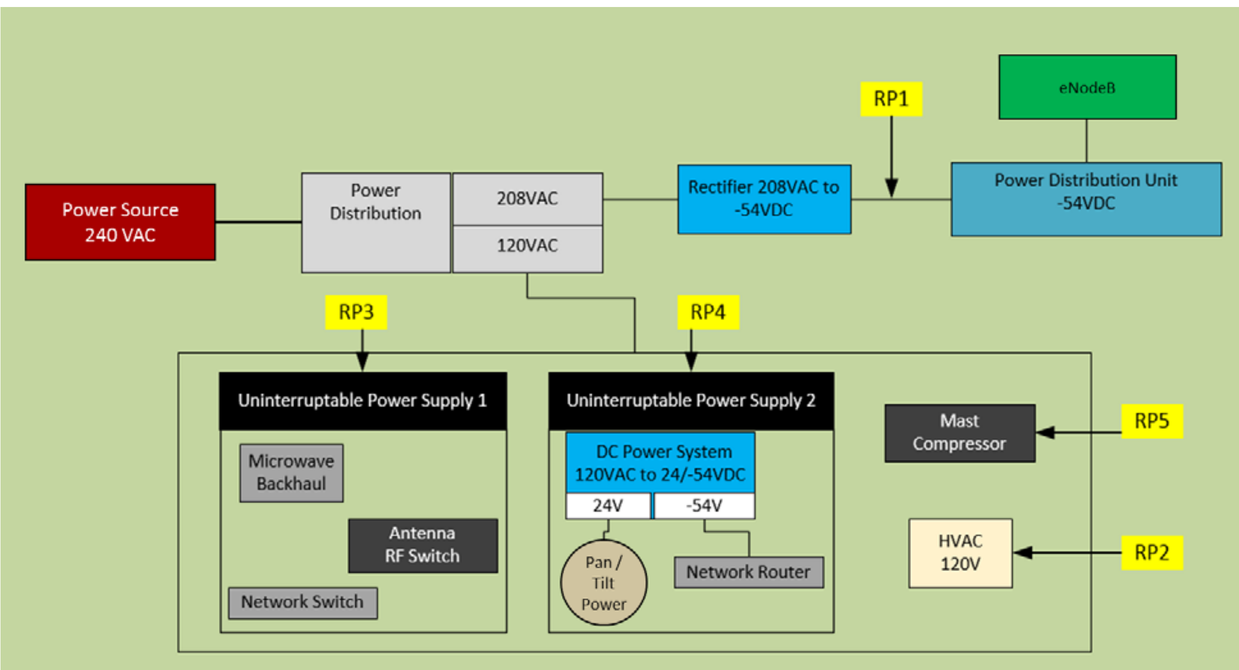

Figure 11 - Test 3 Configuration

Figure 12 below graphically depicts the power consumption measured at the various analyzers during this test.

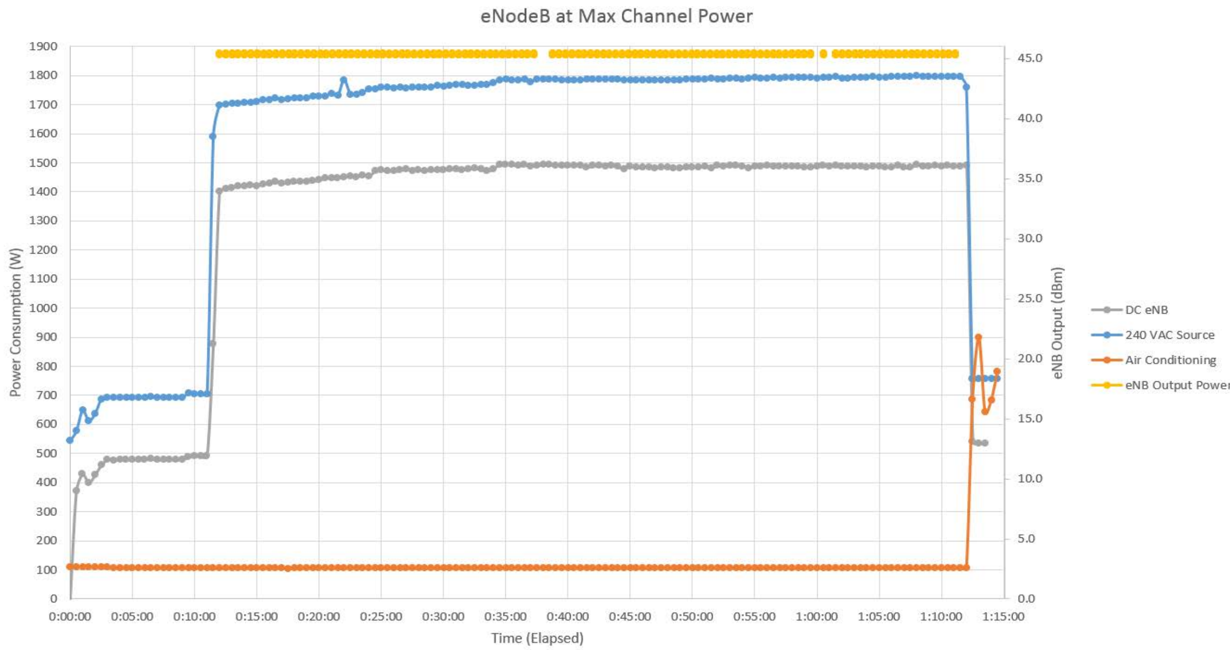

Figure 12 - Test 3: Stable, Fully Loaded

From these results, we see that the eNodeB consumption jumped to approximately 1500 W, while the overall consumption seen at main 208 VAC lines rose to approximately 1800 W. During this test, the eNodeB's output remained at approximately 45.5 dBm. Prior to unlocking the eNodeB, its consumption is approximately 500 W. The air conditioner, once again, remained at minimum consumption throughout the majority of the test. It did, however, engage the pump and condenser at approximately the same time that the eNodeB was powered down, raising its consumption to approximately 900 W. When the air conditioner "kicked on," the reading at the main 208 lines did not increase. This tells us that the 120 VAC leg that the air conditioner was on, but was not accounted for by the analyzer at RP2. An extra 300 W was unaccounted for.

3.3.3.4 Test 4 – COW HVAC Operations

The HVAC system integrated into the COW under test is designed with a thermostat, which engages the HVAC if the equipment temperature rises above a given threshold. On this particular system, there was no way to control the HVAC system manually. To that end, the COW remained in a powered-on state, for a long duration, to capture any instances of HVAC utilization.

The measurement point for this test was the 120 VAC input to the HVAC system (Reference Point 3 in Figure 18). Figure 13 graphically depicts the power consumed during the test execution.

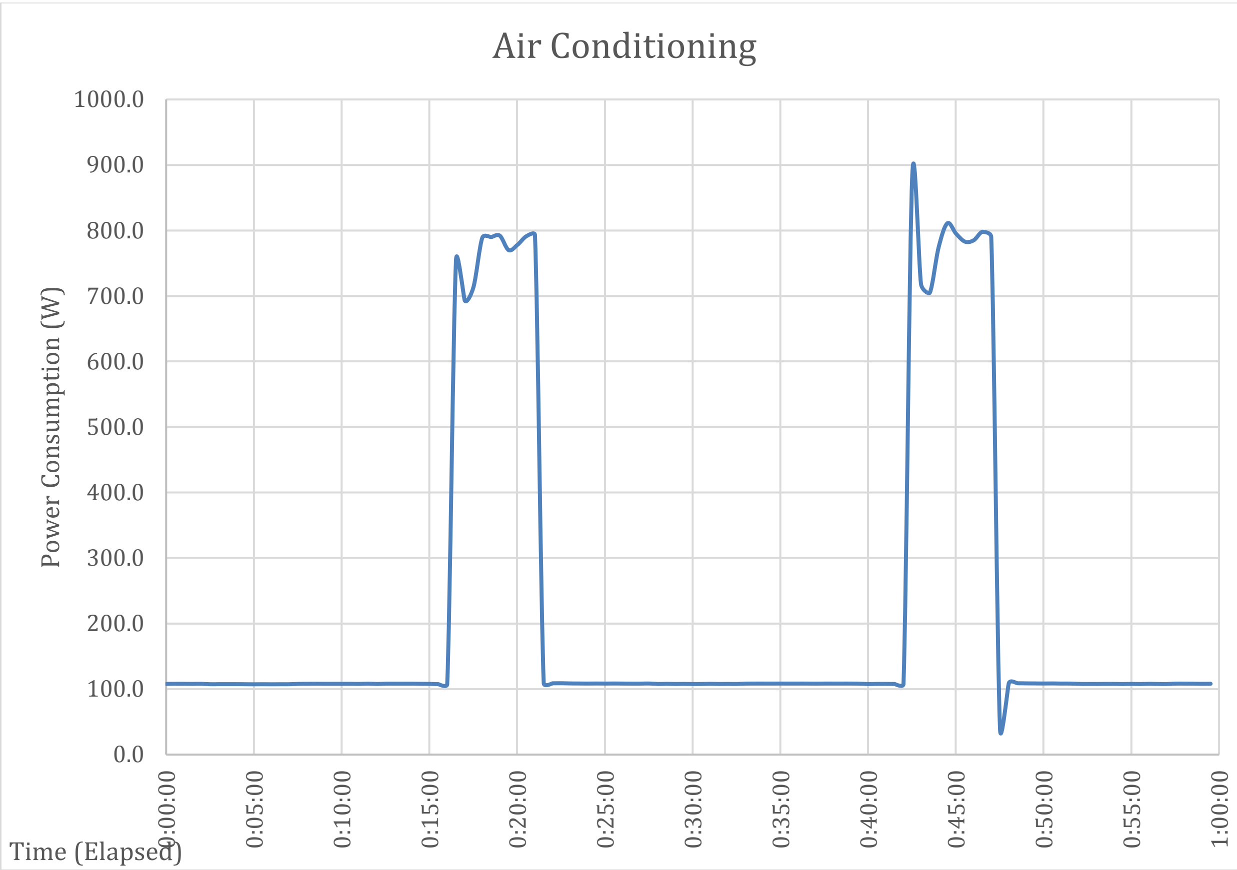

Figure 13 - Test 4: HVAC Operations

During the conduct of this test, the ambient air temperature ranged between 57°F and 61°F. It was observed that the fan ran continually, drawing approximately 107 W, with a power factor of 1. The HVAC unit engaged twice during this period for approximately five minutes (each occurrence).

It was also observed that the average consumption during full operation was approximately 775 W. The highest power draw observed was 884 W, with a power factor of 0.8.

3.3.3.5 Test 5 – COW Uninterruptable Power Supplies Power Draw

The final test was to evaluate the power draw from the two Uninterruptable Power Supplies (UPSs) on the COW. These UPSs are powered by 120 VAC, therefore the 120 VAC reference point on both UPSs were utilized as depicted in Figure 14 below.

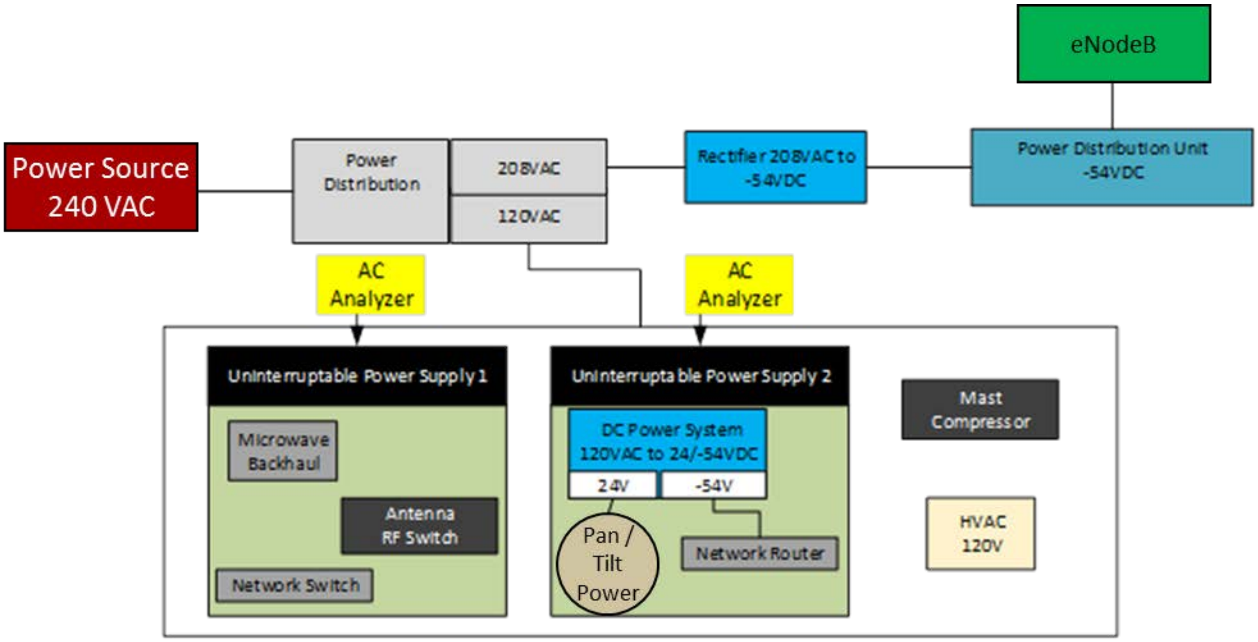

Figure 14 - Test 5 Configuration

Figure 15 below graphically depicts the power consumption of the UPSs.

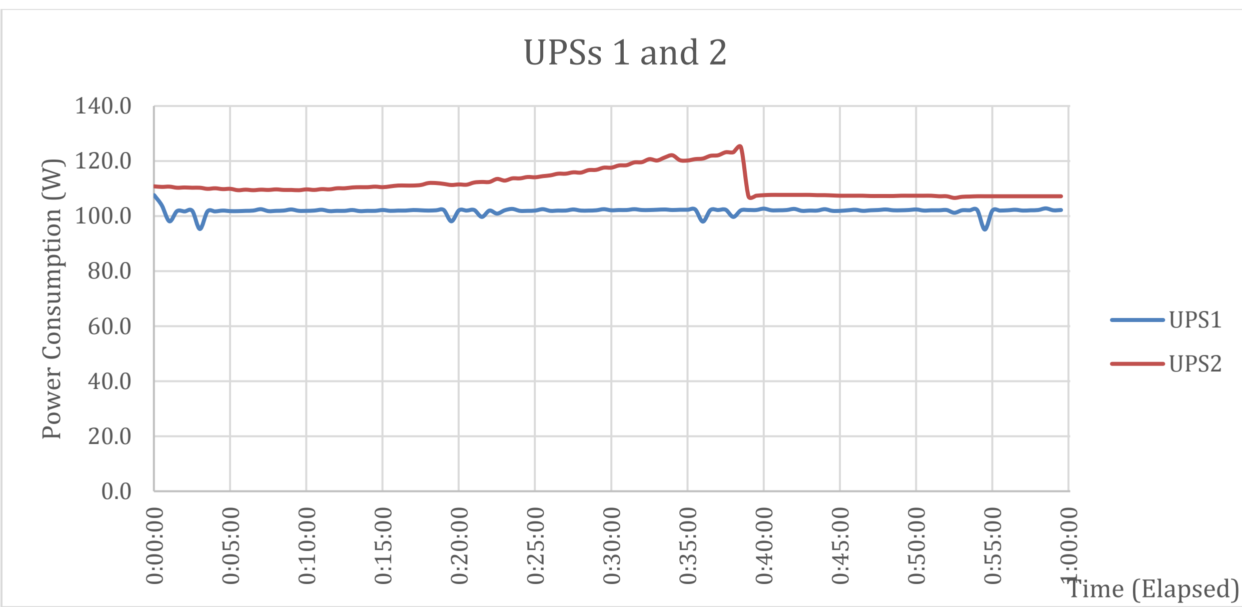

Figure 15 - Test 5: UPS Consumption

UPS 1 utilized an average of 102 W during operation. The curve for UPS 2 increased over the first 40 minutes of the test (attributed to the charge cycle for its internal batteries); stabilizing at 107 W after battery charging was completed. Over the span of the test, maximum consumption from these two points was less than 240 W.

3.3.4 Test Equipment (Portable DS)

The following tools were used for collection of data from the portable DS:

- Extech Instruments 380803 AC Power Analyzer
  - Accuracy: ± 0.5% of voltage and current reading
  - Calibration traceable to NIST
- Mini-Circuits ZFRSC-123-S+ RF Power Splitter
  - DC – 12 GHz
  - ~ 9.7 dB loss (manufacturer spec)
  - ~ 21.7 dB loss (tested with additional 10 dB attenuator)
- Fairview Microwave SA6N 10W-10 Attenuator
  - DC – 6 GHz
  - 10 dB attenuation
  - 10 Watt max input power
- Agilent E4419B Power Meter
  - +21.7 dBm offset added to signal to compensate for in-line attenuation
- Agilent E9300A Avg Power Sensor
- iperf UDP traffic generator
  - UDP downlink attempted = 70 Mbps/UE per iperf session

3.3.5 Portable Deployed System Measurements

As noted in Section 3.3.1, the testing strategy for portable DS required a different approach from that used with the COW, due to differences in the design and intended use between the two systems. The purpose of the power analysis of the portable LTE DS was to determine this system's power consumption relative to its RF power output, with the results assumed to be representative of this type of DS. In contrast to COW systems, which are widely deployed by commercial carriers, portable LTE deployable systems are still evolving; differences in architecture decisions and design parameters are expected to result in significant variation between systems. Future tests of other vendors' rack-mount systems may converge to produce an expected average (or maximum) power consumption value for these types of systems.

For this test, the AC and RF analyzers were placed as shown in Figure 16.

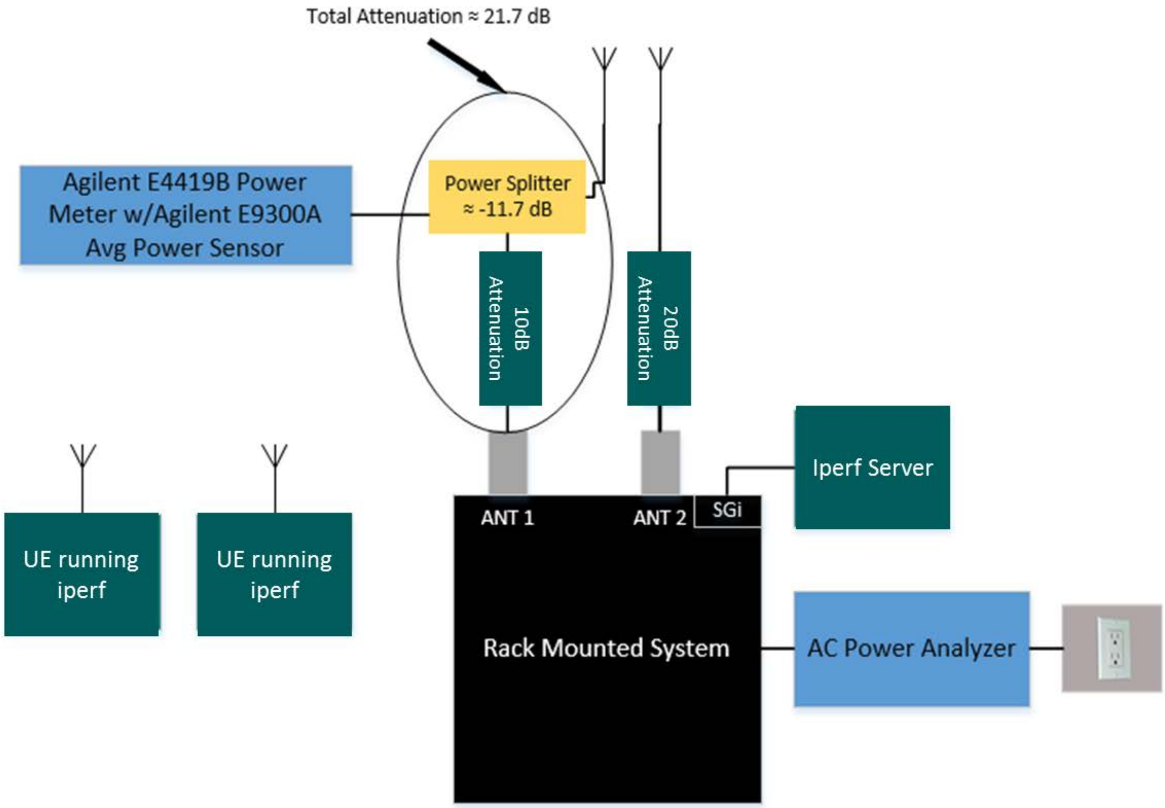

Figure 16 - Portable LTE Deployable System Power Assessment Test Setup

As shown in Figure 17, there is an increase of approximately 33 W when downlink traffic is pushed to the max (~58 Mb/s). Also, the channel power increases by approximately 9 dBm (approximately triples the idle output power).

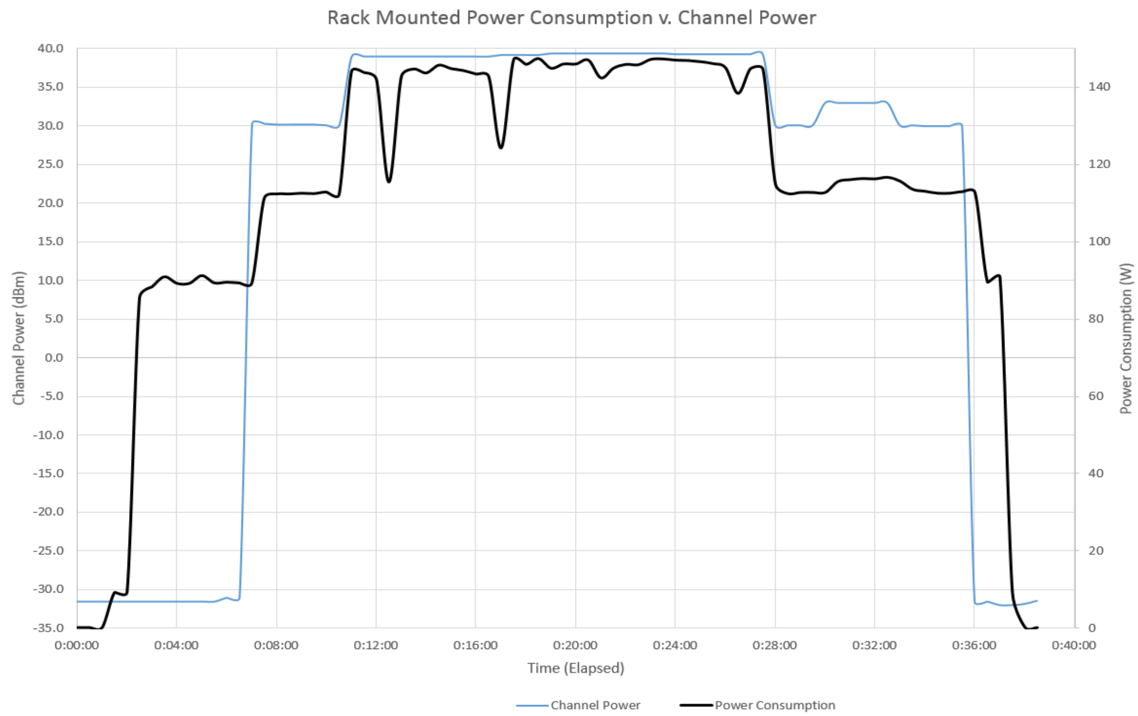

Figure 17 - Portable DS Power Consumptions Versus RF Transmitting Power

Overall Power Consumption:

- No traffic (~ 30 dBm) ≈ 112 W
- Max traffic (~ 39 dBm RF power) ≈ 145 W

The difference in power consumption of this rack mount type system, between no traffic and max traffic, is considered minimal.

4 Summary and Significance of Findings

This paper describes an assessment of operational power consumption by a public safety COW and man-pack portable DS at PSCR. The power consumption was measured in three scenarios: 1) deployment; 2) unloaded steady state; and 3) fully loaded operation. Additional devices, such as the UPS and the HVAC, were measured independently. The goal of the assessment was to identify the major power-related components of the DS under test, and obtain power measurements for individual components to determine the operational endurance based on known quantities of power generated (or stored) and consumed by the DS. Although the information and findings reported here come from the assessment results of the DS types under test, comparisons with other products may be derived by scaling the power-related components of similar DS.

For this effort, the major components relating to power generation and consumption of two DS were first identified, and the power assessment was divided into two phases. This report documents the evaluation results for Phases I and II of the project.

4.1 Phase I Findings

Tests were conducted to determine which components of the COW DS under test, with a three-cell eNodeB, would consume the greatest portions of the generated power. With each of the six TX ports transmitting at 46 dBm in fully loaded operation, or at 36 dBm in unloaded steady state, the eNodeB consumed the majority of the generated power, followed by the HVAC. The power consumption ratio of the eNodeB to HVAC was at 1.75 to 1 in unloaded steady state and 3 to 1 in fully loaded operation, respectively. Reference table 1 below for summary of COW operational duration.

By method of direct observation, tests were then conducted to assess the operational time. Each test started with the AC generator's fuel tank at full level; the unloaded steady state test lasted for seven hours, and the fully loaded operation lasted for four hours for the COW DS under test.

System State	TX Power	Fuel Consumption (gal/hr.)	Operational Duration (Generator)
Operational, Unloaded Steady State	36 dBm	0.64 GPH	7.0 hours
Operational, Fully Loaded, Steady State	46 dBm	1.1 GPH	4.0 hours

Table 1 - COW Operational Duration

The operational duration also depended on the AC generator's efficiency and fuel tank capacity, the latter of which could be arbitrary.

In the case of the man-pack portable DS, with fully charged battery unit, the LTE unit transmitted at 30 dBm in each of its two TX ports, in fully loaded operation for five hours. In unloaded steady state, the LTE unit transmitted at 17 dBm for seven hours. Table 2 below shows the portable DS operational duration.

System State	TX Power	Operational Duration (Generator)
Operational, Unloaded Steady State	30 dBm	7 hours
Operational, Fully Loaded, Steady State	39 dBm	5 hours

Table 2 - Portable DS Operational Duration

Phase I provided expected operational durations for each of these two representative systems under conditions with no load and maximum user load.

4.2 Phase II Findings

Phase II performed analyses at different points in the COW configuration to gather definitive measurements of specific devices during multiple operational states. Table 3 below shows the maximum power potentially consumed by the entire system during both the deployment and operational phases.

Device	Max Consumption (VA)	Max Consumption (W)	Max Current (208 VDC)
Deployment Phase			
DC PDU (eNodeB)	500	500	
HVAC (120 VAC)	1050	900	
Mast Compressor (120 VAC)	1300	810	
UPS 1	150	110	
UPS 2	145	125	
Total Deployment:	**3145**	**2445**	**~15.12 A**
Operational Phase			
DC PDU (eNodeB)	1500	1500	
HVAC (120 VAC)	1050	900	
UPS 1	150	110	
UPS 2	145	125	
Total Operational	**2845**	**2635**	**~13.68 A**

Table 3 - COW Operational Power Assessment

These results indicate that during initial setup, the installer must account for power of the DC PDU, the HVAC and the Mast Compressor. During operations, the operator must account for the power for the DC PDU and the HVAC. Everything else in use consumes under 240 W, contributing minimally to the overall power requirement. In the particular system under test, the 240 W was not significant since the power source capacity was rated at 5500 VA.

The power assessment results for portable DS are shown in table 4 below.

Device	Max Consumption (VA)	Max Consumption (W)	Max Current (Ampere)
Deployment Phase			
Unloaded Steady State	114	112	0.95
Operational Phase			
Fully Loaded Operational State	146	145	1.2

Table 4 - Portable DS Operational Power Assessment

5 Appendix

5.1 COW Power Measurement Reference Points

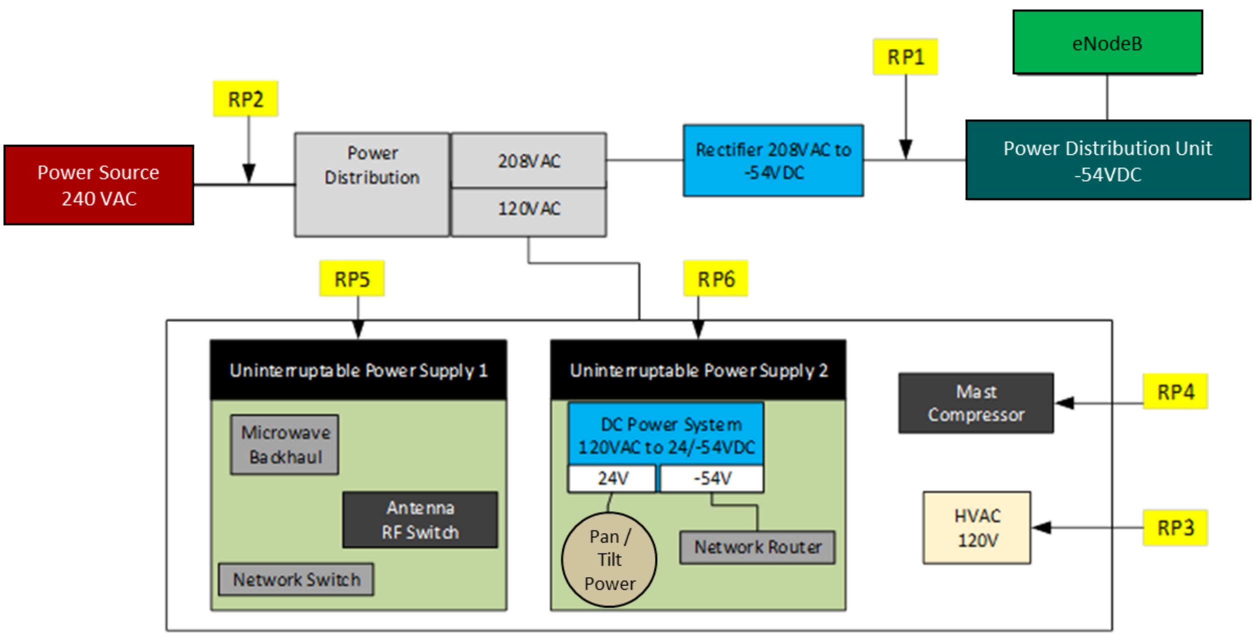

Figure 18 - COW Power Measurement Reference Points

5.2 Cell on Wheels (COW) Detailed Power Layout

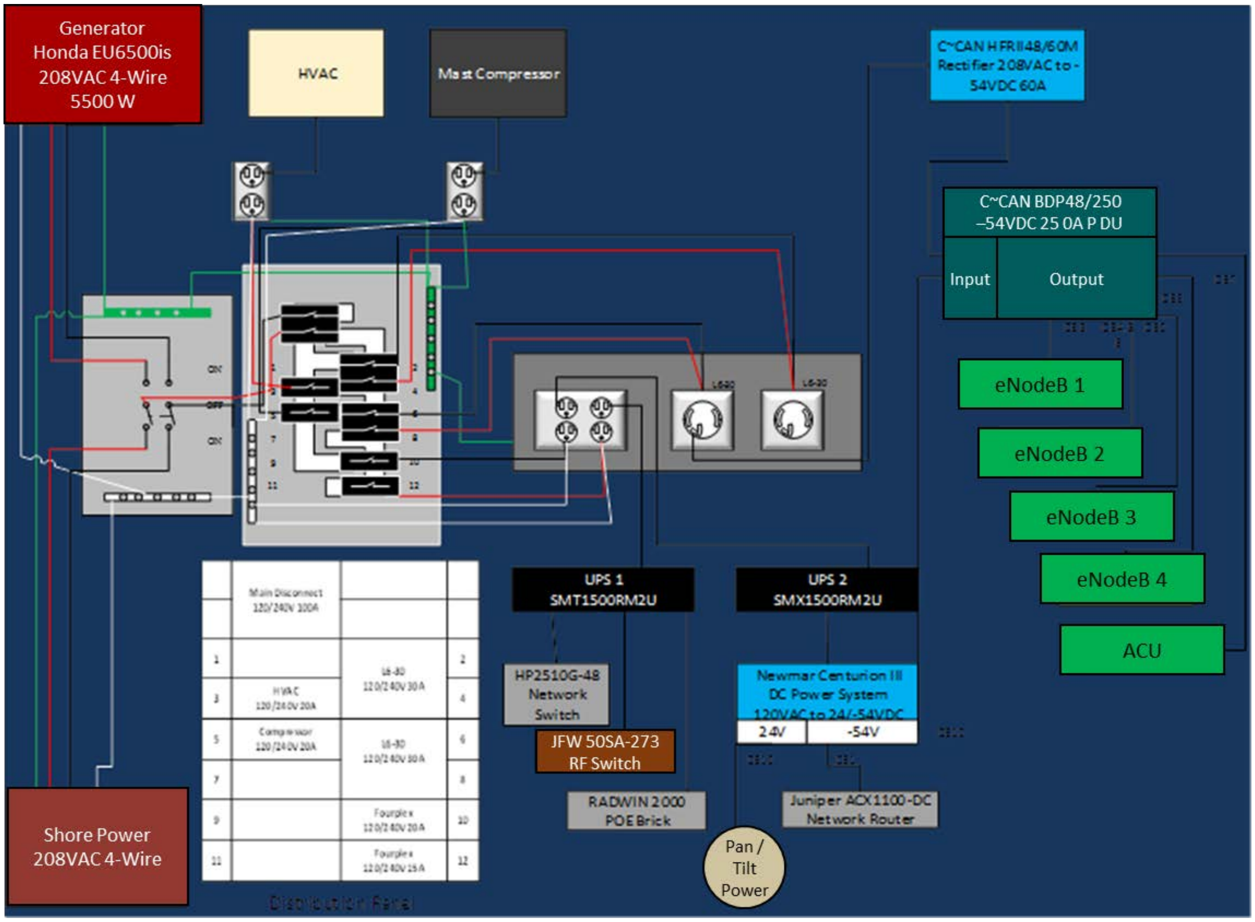

Figure 19 - COW Detailed Power Layout

Figure 19 shows the physical layout diagram of the power connections (ac and dc) of the COW.