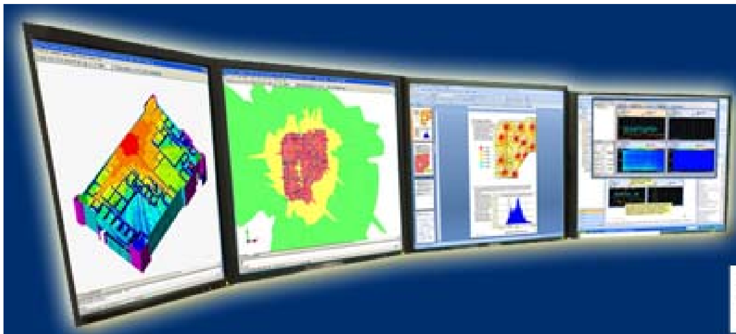

Connect EZ® Predictive RF CAD Design

University of California Santa Cruz

Building 7919
Physical Sciences Building (PSB)

Santa Cruz, California

August 29, 2014

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RF ANALYSIS AND PREDICTIVE MODELING

This report combines the results of on-site RF spectrum analysis with predictive, 3-dimensional computer modeling and simulation to present a comprehensive view of the wireless network environment.

Wireless data networks transfer packets of information by representing bits using specifically defined fluctuations in a transmitted carrier signal. To properly assess the characteristics of a site it's necessary to evaluate both the data being transferred and the radio signals being transmitted. Packet-level analysis tools are used to evaluate data and spectrum analyzers are used to evaluate the RF environment and transmitted signals to assess throughput and capacity along with the assessment of RF noise, interference, signal strength, and coverage area.

By applying 3-dimensional RF CAD modeling and simulation, propagation and signal behavior models both extend the analysis of the site and present the results in a clear, graphical format. It has been demonstrated that an accurate model can match empirical measurements to within ±2dB.

Disclaimer and Perspective on RF Analysis and Modeling

Every effort has been made to provide accurate, reliable information and to draw valid conclusions. If you base any decisions on the information in this document, or on any other discussions with the RF engineering, sales or management team, you accept all liability for consequences arising from those decisions. You must consider the following points when applying the contents of this document to anything:

- Component data are extracted from catalogs, brochures, and web page material provided by various vendors. Component specifications may change without notice and individual manufacturing tolerances, equipment damage, or incorrect installation may result in variations from published equipment specifications.
- The RF environment is subject to influences that may not be anticipated. Findings presented in this report reflect the state of the RF environment at the time the measurements were taken. Every effort has been made to confirm that the measurements are representative of the typical state of the environment but that environment may change without any obvious visible indication.
- Architectural plans used in the preparation of this document may be incomplete, inaccurate, or inappropriate for their intended purpose. On-site measurements of specific characteristics of any building materials performed in conjunction with this document may not comprise all materials throughout the site. All attenuation values, material composition descriptions, and site characteristics not specifically measured at the site were obtained from sources believed to be correct but not independently verified.
- Information obtained from subject matter experts and other authoritative sources may be used without independent validation and may be inaccurate.
- The electromagnetic characteristics of any space are affected by a variety of complex interactions ranging from the 11-year sun spot cycle to microwave ovens and cordless phones. It is impossible to anticipate, evaluate, or model all of the possible environmental influences that may cause the conclusions in this document to be invalid.

If you base any decisions on the information contained in this document you acknowledge that you have carefully considered the potential for error and you accept that risk. The data in this report is provided on an as-is basis with no warranty or guaranty for accuracy. No warranty, express or implied, is made concerning consistency with any standard of merchantability, or that the information provided will meet your requirements for any particular application.

The information in this report must not be relied upon for implementing a transmission system whose incorrect design, installation, or use could result in injury to a person or loss or damage to property, including but not limited to intellectual property or computer data.

Any liability shall be limited to a refund of all monies paid to obtain this report and there shall be no liability for loss or injury caused by its actions, omissions, or for contingencies beyond its control nor for decisions made or action taken or not taken in reliance upon the information furnished in this document.

IMPORTANT INSTALLATION GUIDELINES

PLEASE READ CAREFULLY BEFORE YOU BEGIN INSTALLING EQUIPMENT:

Our experience has been that post-installation validation of designs based on RF CAD modeling and simulation confirm that actual signal strength is highly consistent with predicted values. Nonetheless, **field validation of the present design must be performed at the time of installation to avoid potentially costly and time consuming problems** after end-users begin to access the system. Those responsible for the installation of the system must assure that the assumptions made in this design, and the equipment specifications used in creating the models, are correct. The confirmation process includes the following steps that must be performed as equipment is installed:

Upon installing the FIRST radio on each building floor:

1. Use a measuring tool that reports dBm or mW signal strength and confirm that actual coverage is consistent with predicted coverage. The tool could be as simple as NetStumbler or as sophisticated as AirMagnet (or an actual RF spectrum analyzer.) If measured signal strength is below the Design Signal Strength for the present project (discussed on in the Design Signal Strength section of this report) you should **STOP THE INSTALLATION PROCESS** and call to discuss the discrepancy. Not only is this type of validation considered standard practice, it is also the most effective way to avoid future problems.
2. Connect to the SSID of the access point and use the MS-DOS PING command to confirm data transfer capability across the wireless link. This may require that you manually configure the IP address of your notebook computer to match the subnet of the access point's management interface. Use the "-t" option with PING to continuously send ping packets. Walk around the intended coverage area for the access point and confirm that ping responds properly. 802.11 wireless networks typically have error rates that can approach 10% so expect an occasional lost PING packet. If you experience greater than 10% lost PING packets, **STOP THE INSTALLATION PROCESS** and call to discuss the problem. This may require that an RF engineer be dispatched to the installation site to perform a spectrum analysis and isolate the cause of the data loss. Dispatching and engineer to the site may be a separately charged service.

Perform the preceding two steps in any critical or error-prone installation location

Access points intended to provide coverage for the most important locations should be validated as described above. Also, when a coverage area contains known sources of environmental noise or interference, the same steps should be performed.

Do NOT install an entire system without testing and validating during the installation process.

EXECUTIVE OVERVIEW

RF System Design Utilizing CAD Modeling and Simulation

This report provides Installer's Working Plans to support the installation of a WiFi system utilizing Cisco 2600-series 802.11n access points to support Voice-over-IP and high-throughput WiFi in both the 2.4 GHz and 5 GHz bands.

Site characteristics that would impact RF transmission and reception were identified and antennas were placed for proper radio performance, ease of installation, and aesthetics.

"Installation Version" Design Report

This RF design report is presented in requested Connect802 "Installation Version" format. In this format the stepwise details of the RF CAD modeling and simulation process are not presented but, rather, only the resulting Installer's Working Plans drawings are provided.

Access Point Counts

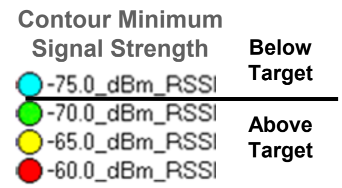
The table below summarizes the access point counts for the present design:

Floor	Cisco 2600 (Indoor)	Cisco 2600 (Outdoor)
1	14	
2	15	
3	19	
4	15	
5	4	
Total	**67**	**0**

5.8 GHz DESIGN SPECIFICATIONS

The present design provides an average **-75 dBm** signal level throughout the specified coverage area. A client device, in general, can expect to be in a location where signal strength is at or above **-65 dBm**.

To achieve this result, predictive RF CAD models have been created that require a target design signal strength of **-65 dBm**. This target signal strength is depicted on Grid Coverage Models in the present report using the color legend shown to the right.



Supported Air Standards	**802.1n**
Assumed Average Background Noise and Interference	**-100 dBm**
Access Point Transmit Power	**17 dBm (5.8 GHz)**
Access Point Antenna Gain	**4 dBi**
Access Point Cable/Connector Loss	**0 dB**
Access Point Body Loss	**0 dB**
Resulting Access Point EIRP	**21 dBm**
Client Device Transmit Power	**17 dBm (5.8 GHz)**
Client Device Antenna Gain	**2.2 dBi**
Client Device Cable/Connector Loss	**0 dB**
Client Device Body Loss	**3 dB**
Resulting Client Device EIRP	**16.2 dBm**
Specified Minimum RSSI for Real-World Implementation	**-75 dBm**
Resulting Signal-to-Noise-Ratio (SNR)	**30+ dB**
Coverage Cell Overlap Boundary RSSI (Calculated)	**-63 dBm**
Coverage Cell Overlap Percentage (Default / Standard)	**20%**
Coverage Cell Overlap Factor (Calculated)	**1.9 dB**
Design Body Loss	**0 dB**
Fade Margin	**10 dB**
Resulting Current Design Target RSSI for Predictive Models	**-65 dBm (5.8 GHz)**

EQUIPMENT SPECIFICATIONS

Cisco 2600 Series 802.11n Access Point

- 3X4:3 MIMO
- 802.11n and 802.11a/g beamforming
- 802.11 Dynamic Frequency Selection (DFS)
- Integrated 4 dBi antenna (2.4 and 5 GHz)
- Non-Overlapping 5 GHz 20 MHz Channels: 21

Available transmit power settings	2.4 GHz	5 GHz
	• 22 dBm (160 mW) • 19 dBm (80 mW) • 16 dBm (40 mW) • 13 dBm (20 mW) • 10 dBm (10 mW) • 7 dBm (5 mW) • 4 dBm (2.5 mW) • 2 dBm (1.25 mW)	• 23 dBm (200 mW) • 20 dBm (100 mW) • 17 dBm (50 mW) • 14 dBm (25 mW) • 11 dBm (12.5 mW) • 8 dBm (6.25 mW) • 5 dBm (3.13 mW) • 2 dBm (1.56 mW)

Connection Rate (Mbps)	2.4-GHz 802.11n (HT20)	5-GHz 802.11n (HT20)	5-GHz 802.11n (HT40)
6.5	-91 dBm @ MCS0	-92 dBm @ MCS0	-89 dBm @ MCS0
13	-90 dBm @ MCS1	-91 dBm @ MCS1	-88 dBm @ MCS1
19.5	-90 dBm @ MCS2	-90 dBm @ MCS2	-87 dBm @ MCS2
26	-88 dBm @ MCS3	-87 dBm @ MCS3	-84 dBm @ MCS3
39	-85 dBm @ MCS4	-84 dBm @ MCS4	-81 dBm @ MCS4
52	-80 dBm @ MCS5	-80 dBm @ MCS5	-76 dBm @ MCS5
58.5	-78 dBm @ MCS6	-78 dBm @ MCS6	-74 dBm @ MCS6
65	-75 dBm @ MCS7	-75 dBm @ MCS7	-73 dBm @ MCS7
13	-90 dBm @ MCS8	-92 dBm @ MCS8	-89 dBm @ MCS8
26	-90 dBm @ MCS9	-90 dBm @ MCS9	-87 dBm @ MCS9
39	-89 dBm @ MCS10	-88 dBm @ MCS10	-85 dBm @ MCS10
52	-86 dBm @ MCS11	-85 dBm @ MCS11	-81 dBm @ MCS11
78	-82 dBm @ MCS12	-81 dBm @ MCS12	-78 dBm @ MCS12
104	-78 dBm @ MCS13	-77 dBm @ MCS13	-74 dBm @ MCS13
117	-77 dBm @ MCS14	-76 dBm @ MCS14	-72 dBm @ MCS14
130	-75 dBm @ MCS15	-74 dBm @ MCS15	-71 dBm @ MCS15
19.5	-90 dBm @ MCS16	-91 dBm @ MCS16	-88 dBm @ MCS16
39	-89 dBm @ MCS17	-89 dBm @ MCS17	-85 dBm @ MCS17
58.5	-87 dBm @ MCS18	-86 dBm @ MCS18	-83 dBm @ MCS18
78	-84 dBm @ MCS19	-83 dBm @ MCS19	-79 dBm @ MCS19
117	-81 dBm @ MCS20	-80 dBm @ MCS20	-76 dBm @ MCS20
156	-76 dBm @ MCS21	-75 dBm @ MCS21	-72 dBm @ MCS21
175.5	-75 dBm @ MCS22	-74 dBm @ MCS22	–70 dBm @ MCS22
195	-74 dBm @ MCS23	–73 dBm @ MCS23	-69 dBm @ MCS23

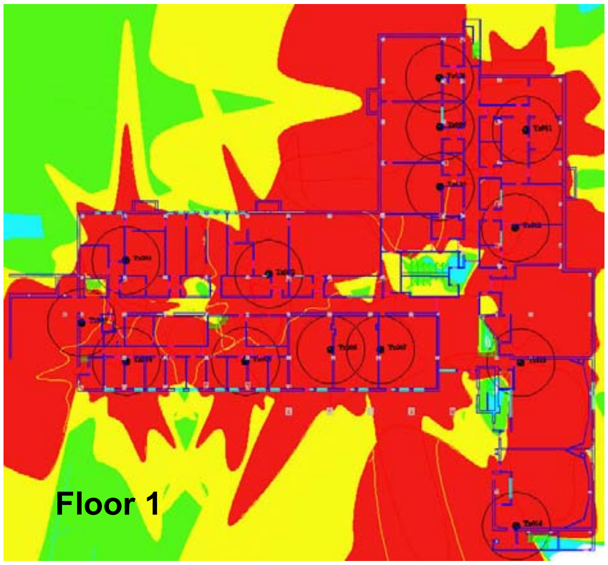
Performance With Standard Guard Interval (GI): 800ns

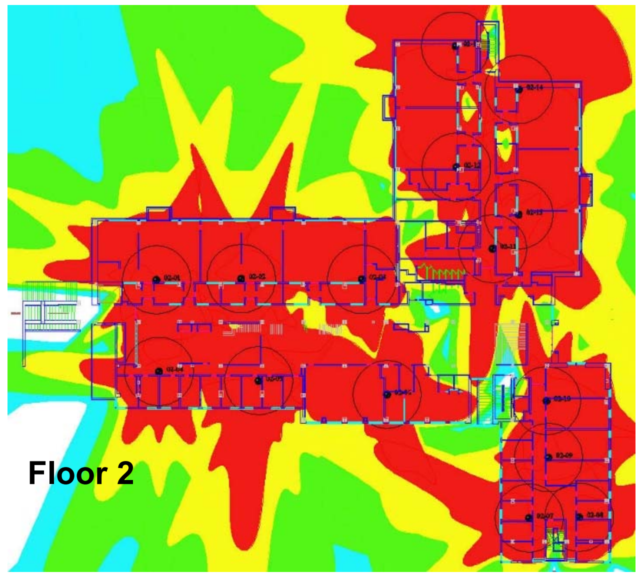
RF COVERAGE MODELS

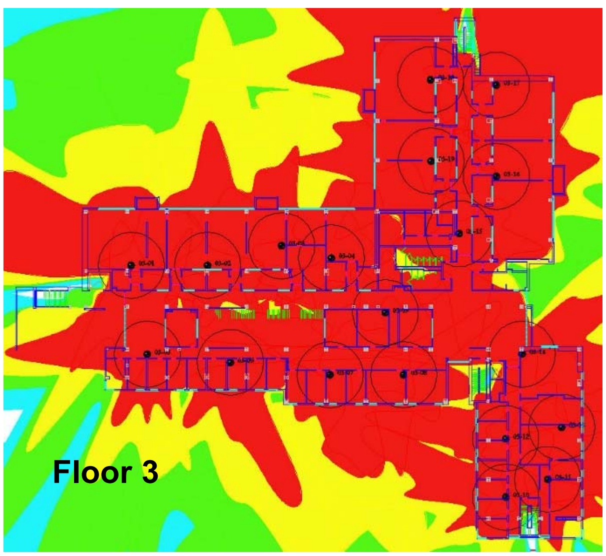
Physical Sciences Building (PSB) 7919 Full Floor Contour Coverage

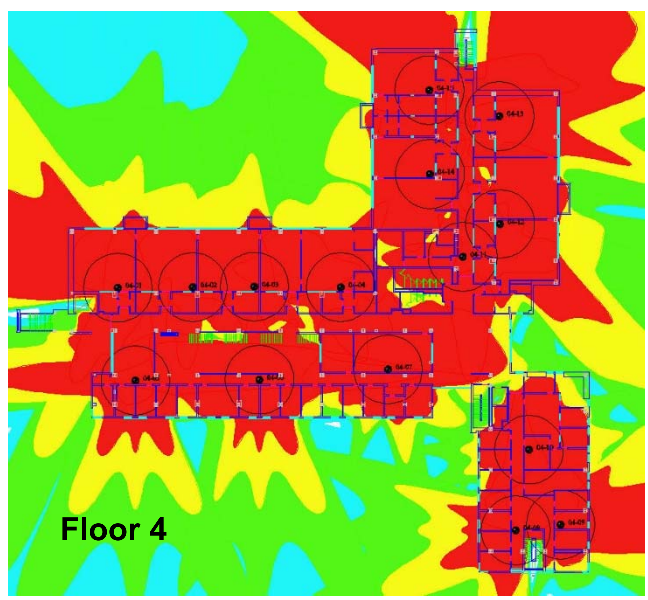
Contour Minimum Signal Strength

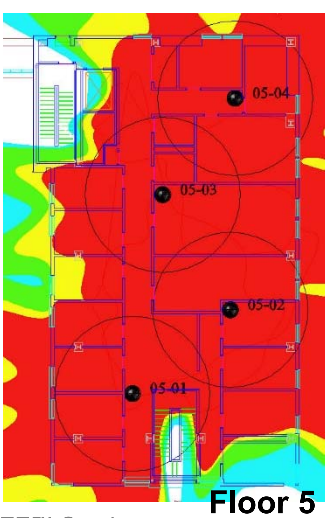
Signal Strength	
-75.0_dBm_RSSI	Below Target
-70.0_dBm_RSSI	Above Target
-65.0_dBm_RSSI	Above Target
-60.0_dBm_RSSI	Above Target











INSTALLER’S WORKING PLANS

Cisco Deployment Recommendations

Installer’s should be familiar with the Cisco Aironet 1600/2600/3600 Series Access Point Deployment Guide (Document Number EDCS-1188900, available on-line on the Cisco website or through a Google search.) This guide provides detailed information regarding the physical installation of the access points specified in this report. The present design assumes that the access points will be installed in accordance with Cisco’s recommendations.

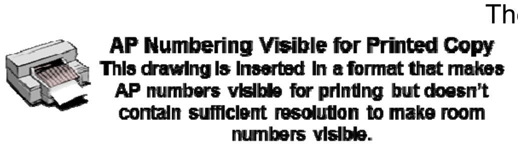
Key Installation Guidelines

Access points should be installed in a horizontal orientation. This implies that they will be mounted flush to the ceiling in each indicated location. If it is necessary to mount an access point on a vertical wall then a 90-degree bracket should be used to maintain a horizontal orientation of the access point itself. The pictures below show examples of installation situations where the access point is correctly mounted.

Presentation of Installation Plans

On the pages that follow you’ll find the Installer’s Working Plans provided in two different viewing/printing formats:

AP Numbering Visible for Printed Copy



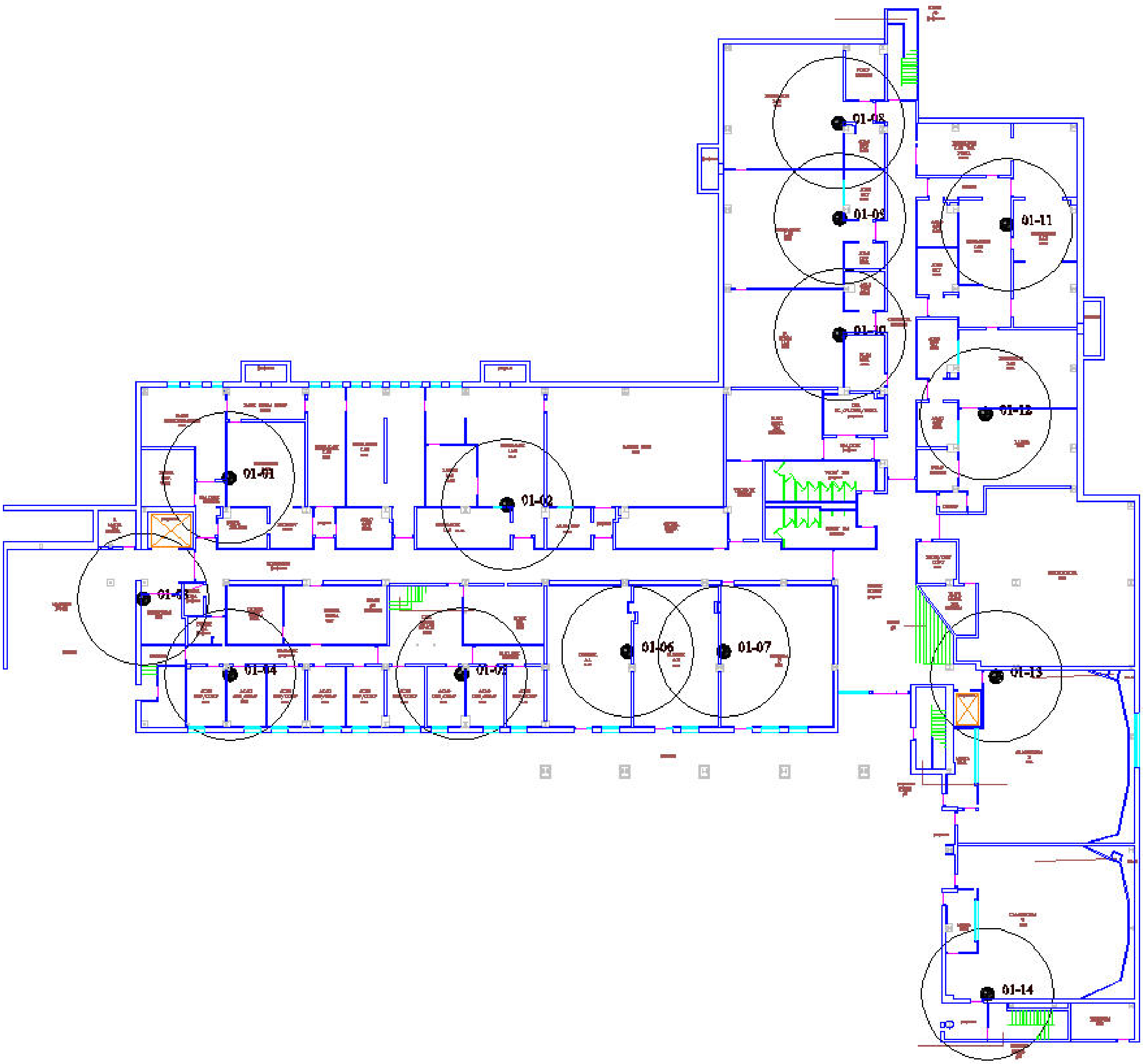
These pages present a .jpg image of the installation plan that has reasonably readable access point numbers and may also have small but readable room numbers. There may be details or small fonts that are pixelated and unreadable in the .jpg image format. These pages are intended for printing.

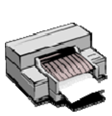
Zoom-In For Detail

These pages have a Windows Media Format (.wmf) embedded floorplan image. This images format is provided specifically for electronic viewing using a PDF document reader. The .wmf format allows you to zoom in to any desired level of detail which will allow reading the smallest fonts (typically room number designations). These images are often not as readable as the .jpg image without first zooming in.

Physical Sciences Building (PSB) 7919
Floor 1 - Installer’s Working Plans

The plan below shows the installation locations based on the previously discussed optimal design.

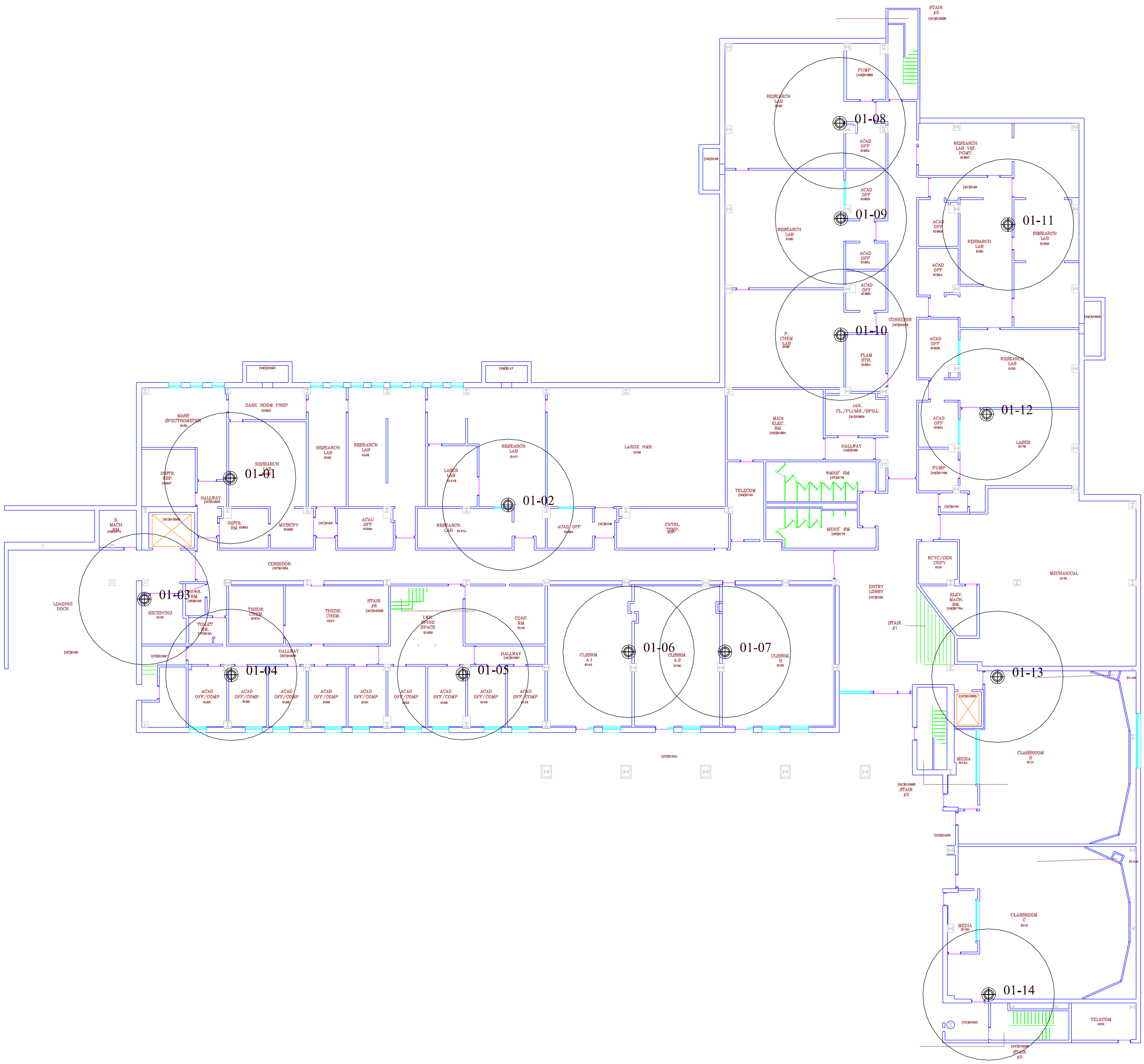




AP Numbering Visible for Printed Copy
This drawing is Inserted in a format that makes AP numbers visible for printing but doesn’t contain sufficient resolution to make room numbers visible.

Physical Sciences Building (PSB) 7919
Floor 1 - Installer's Working Plans

The plan below shows the installation locations based on the previously discussed optimal design.

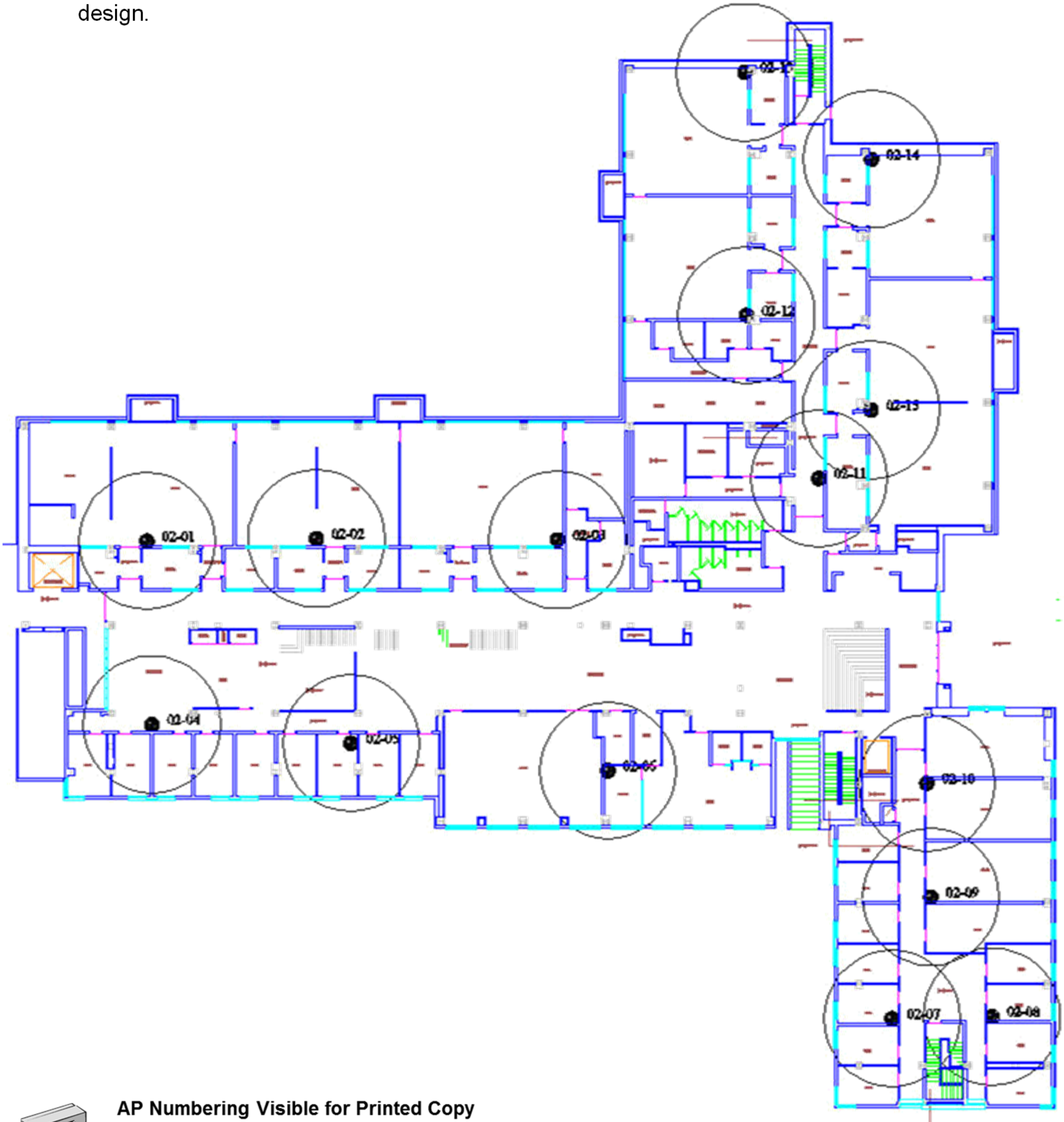


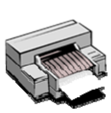
Zoom-In For Detail

This drawing is an inserted image object that allows you to use your viewer's Zoom feature to see maximum detail.

Physical Sciences Building (PSB) 7919
Floor 2 - Installer's Working Plans

The plan below shows the installation locations based on the previously discussed optimal design.





AP Numbering Visible for Printed Copy
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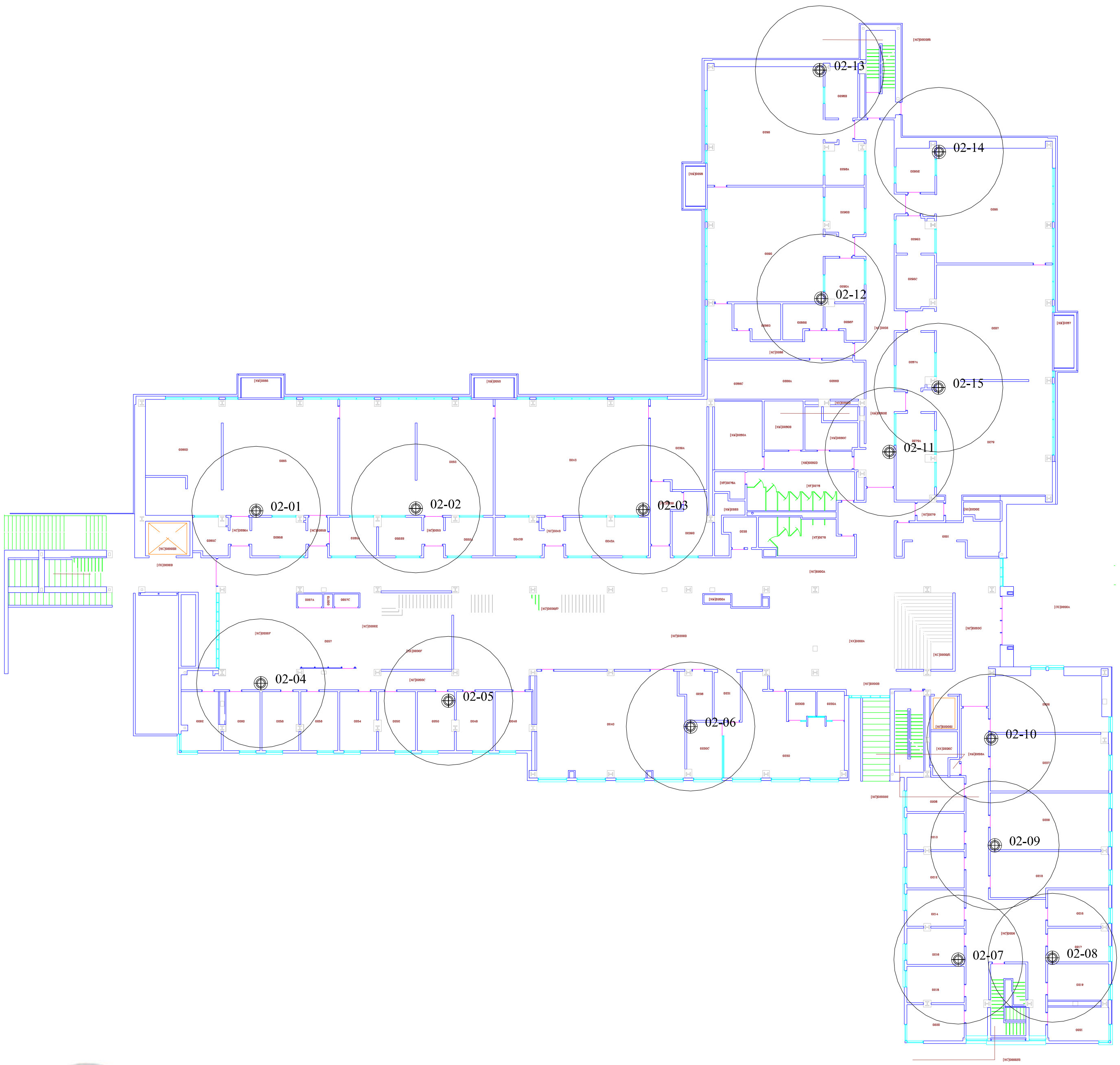
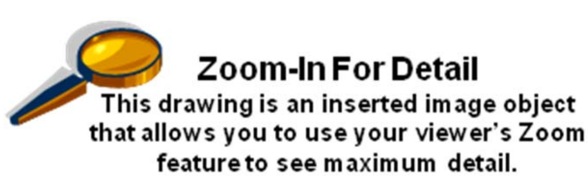
Physical Sciences Building (PSB) 7919
Floor 2 - Installer's Working Plans

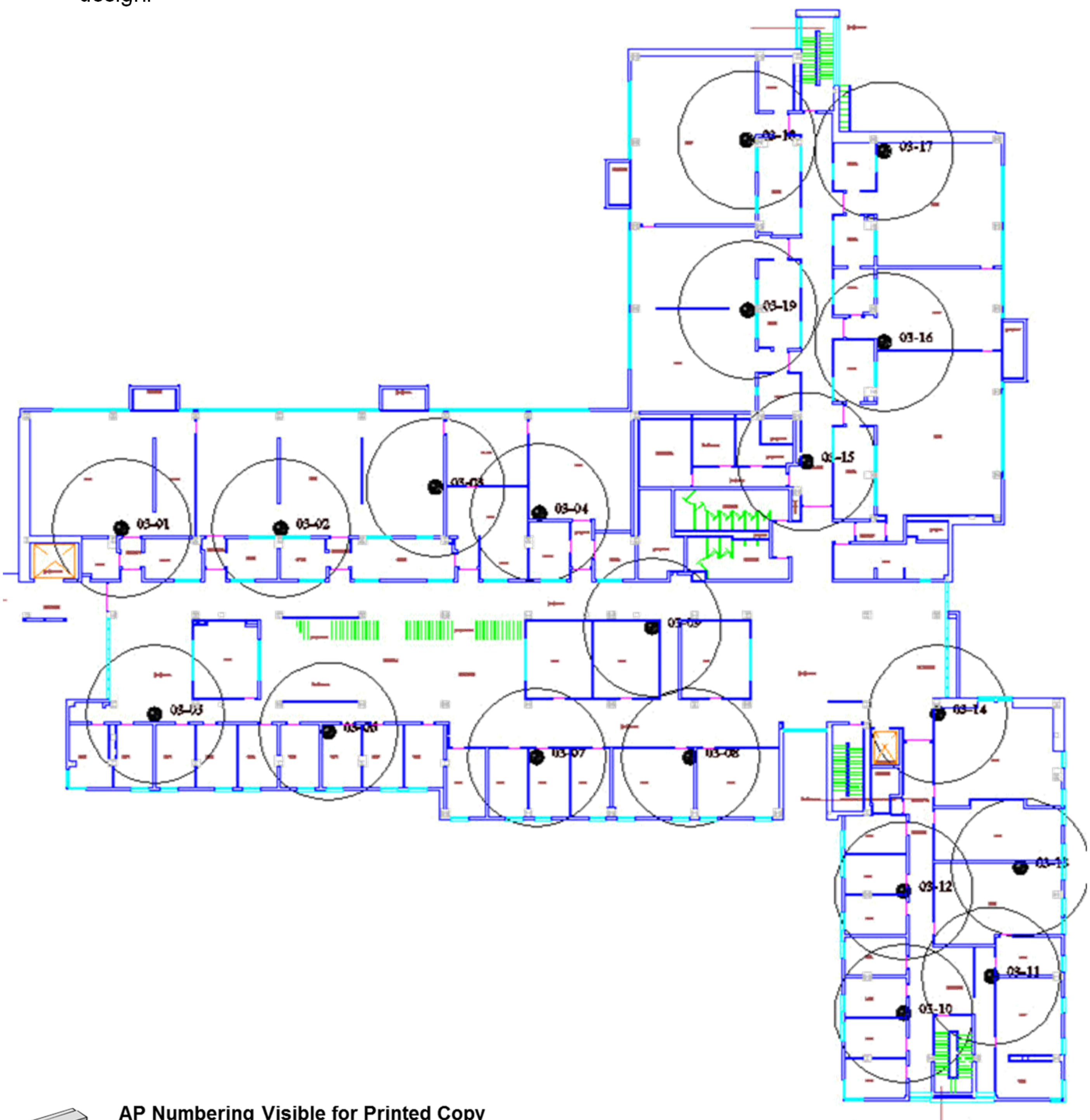
The plan below shows the installation locations based on the previously discussed optimal design.

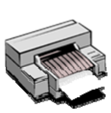




Physical Sciences Building (PSB) 7919
Floor 3 - Installer’s Working Plans

The plan below shows the installation locations based on the previously discussed optimal design.

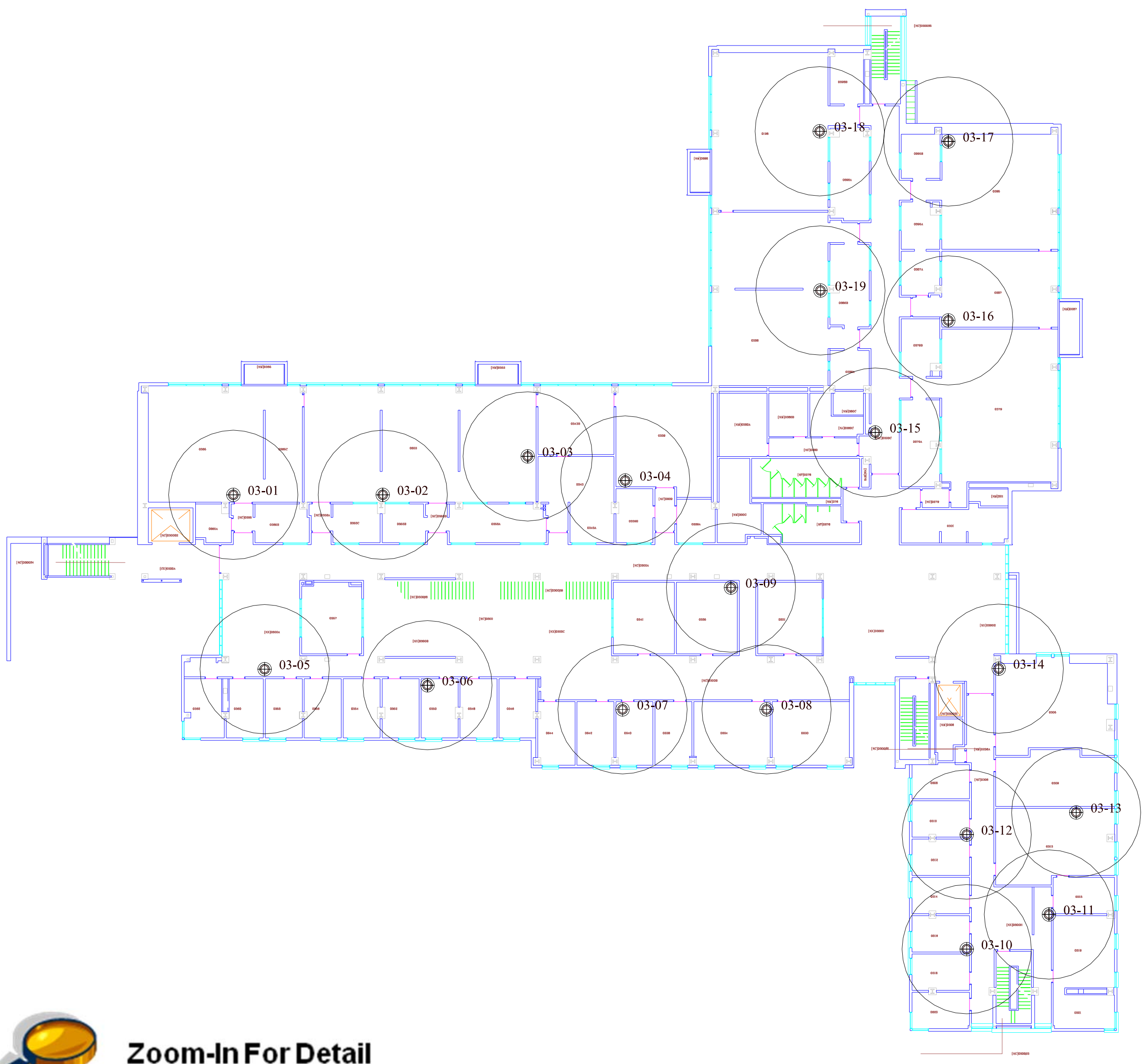




AP Numbering Visible for Printed Copy
This drawing is inserted in a format that makes **AP numbers visible for printing but doesn’t contain sufficient resolution to make room numbers visible.**

Physical Sciences Building (PSB) 7919
Floor 3 - Installer's Working Plans

The plan below shows the installation locations based on the previously discussed optimal design.



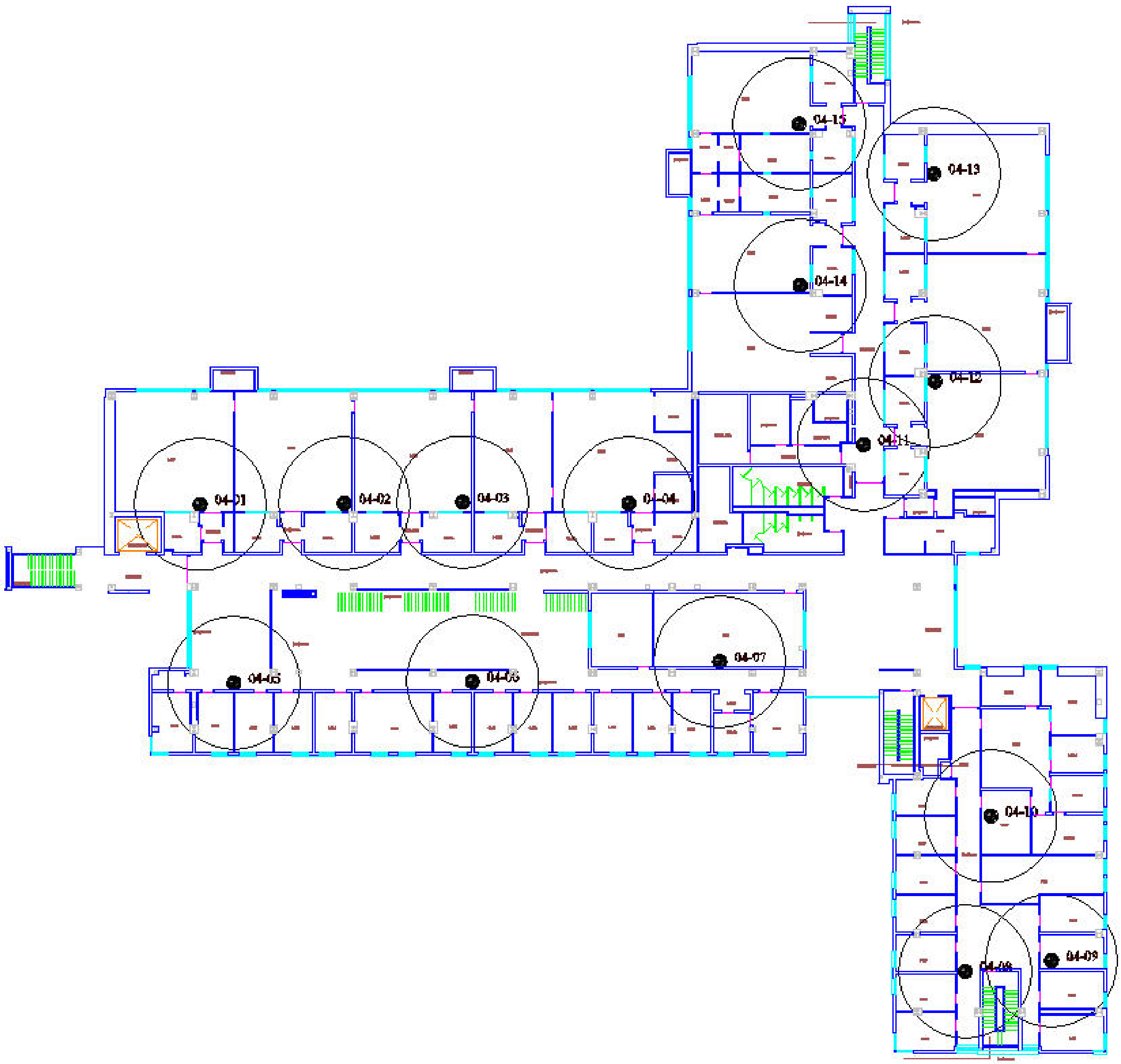
Zoom-In For Detail

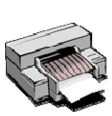
This drawing is an inserted image object that allows you to use your viewer's Zoom feature to see maximum detail.

Physical Sciences Building (PSB) 7919

Floor 4 - Installer's Working Plans

The plan below shows the installation locations based on the previously discussed optimal design.

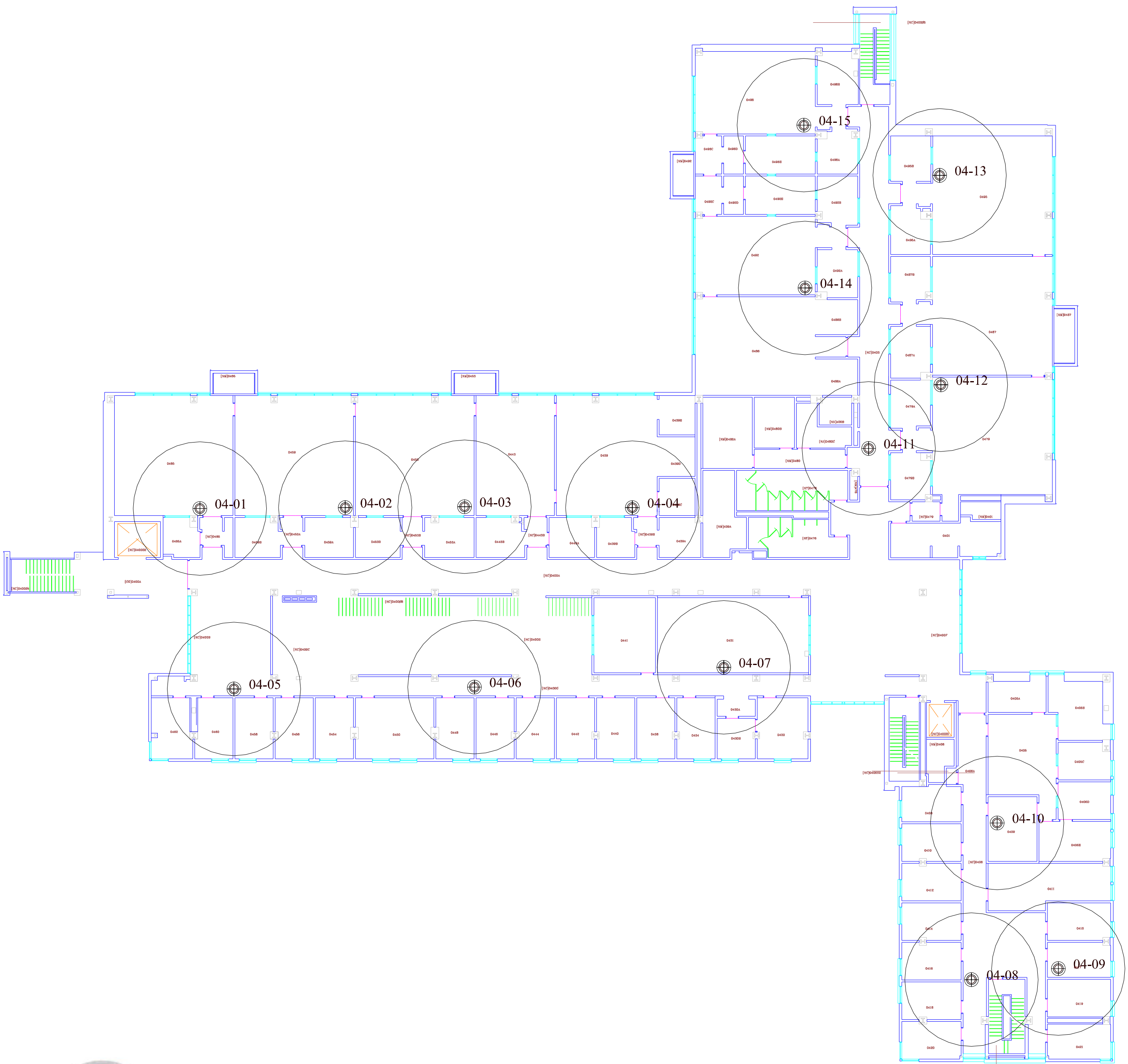




AP Numbering Visible for Printed Copy
This drawing is inserted in a format that makes AP numbers visible for printing but doesn't contain sufficient resolution to make room numbers visible.

Physical Sciences Building (PSB) 7919
Floor 4 - Installer’s Working Plans

The plan below shows the installation locations based on the previously discussed optimal design.

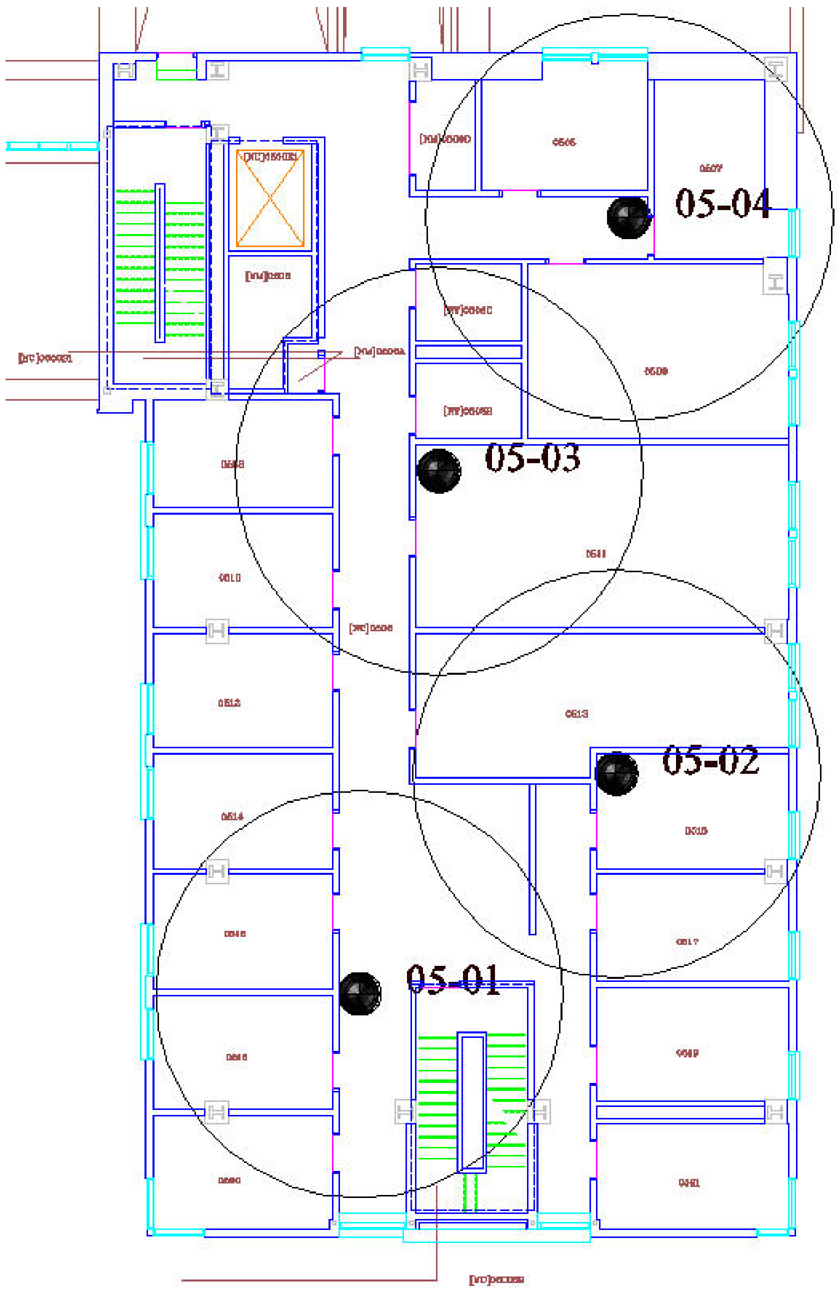


Zoom-In For Detail

This drawing is an inserted image object that allows you to use your viewer’s Zoom feature to see maximum detail.

Physical Sciences Building (PSB) B7919
Floor 5 - Installer's Working Plans

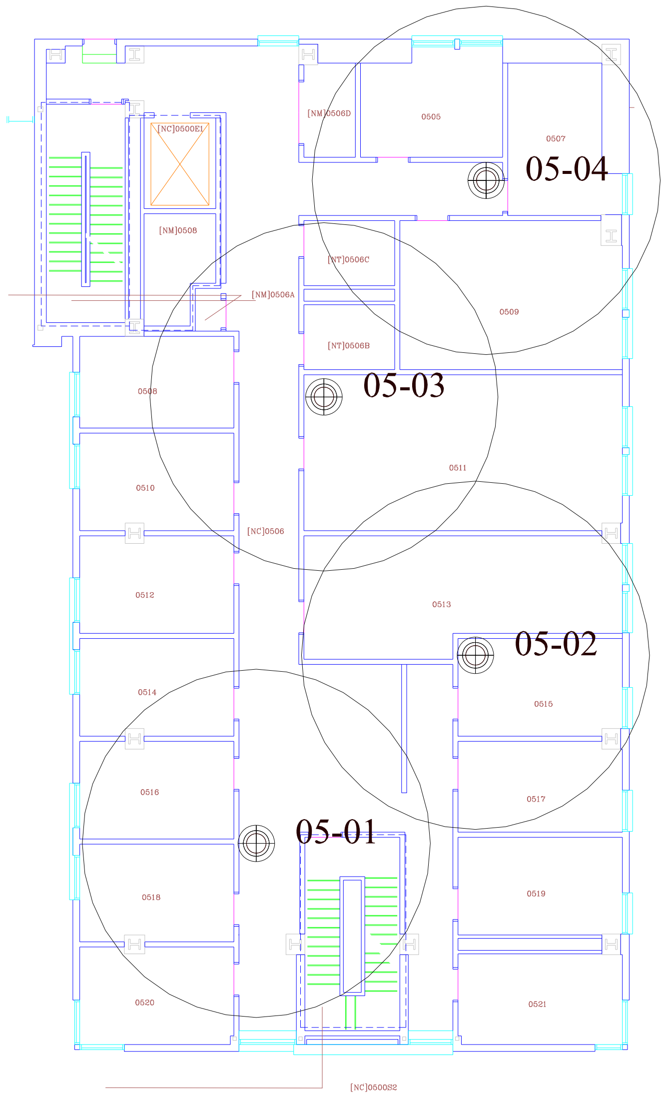
The plan below shows the installation locations based on the previously discussed optimal design.



AP Numbering Visible for Printed Copy
This drawing is inserted in a format that makes AP numbers visible for printing but doesn't contain sufficient resolution to make room numbers visible.

Physical Sciences Building (PSB) 7919
Floor 5 - Installer's Working Plans

The plan below shows the installation locations based on the previously discussed optimal design.



Zoom-In For Detail

This drawing is an inserted image object that allows you to use your viewer's Zoom feature to see maximum detail.

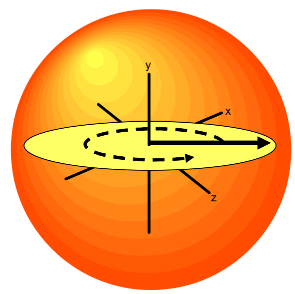
HOW A MODEL IS CREATED

In today's sophisticated engineering disciplines, the use of computer aided design (CAD) to simulate real-world systems is commonplace. Aircraft designers, civil engineers, and even chemical engineers use computer models and simulation systems to test and confirm their designs before putting them into practice. The same engineering sophistication is applied to the design of wireless network communication systems.

The RF modeling and simulation software used to create the design plans presented in this report is based on a number of patented and patent pending technologies and methods. This section describes the model generation process and is intended solely to satisfy the intellectual curiosity of the technically inclined reader. A detailed discussion of RF modeling, including the math and physics underlying the modeling software system, may be found in the book, "Wireless Communications Principles and Practice", by Theodore S. Rappaport (Prentice Hall 2002 ISBN 0-13-042232-0)

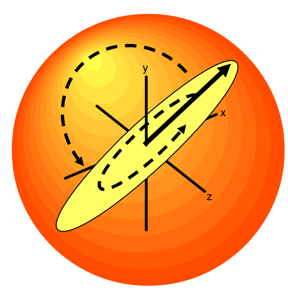
The software system is based on an OEM version of the Autodesk AutoCAD design engine. Overlaid on this engine are a number of plug-in calculation modules that perform path loss measurements, taking into consideration the construction characteristics in a building, the noise factors in the environment, and the effects of co-channel interference, signal reflection, refraction, and diffraction in the space being simulated. When accurate plans are properly formatted the predicted results are typically within ±2 dB of empirical measurements. This accuracy has been confirmed by direct field measurements at various customer sites.

Simulations are calculated in 3-dimensions. A data set is created for each transmitter (and/or receiver) by applying electromagnetic wave propagation formulae to a "ray" extending outward from each transmitter (or inward to each receiver.) The ray is mathematically rotated through 360-degrees in the horizontal plane. The plane is then rotated through 360-degrees with the ray being recalculated in its own 360-degree rotation for each step of the plane. The result is a set of data points describing a spherical volume surrounding each transmitter (or receiver.)



Data points are calculated along a ray rotated through 360-degrees

From the resulting set of data points it becomes possible to calculate the relationships between transmitters both in real-time (during the simulation and antenna placement phase of design work) and for the purposes of report output.



A spherical volume of data points is created by rotating the calculation plane through 360-degrees, repeating the plane calculations at each step.