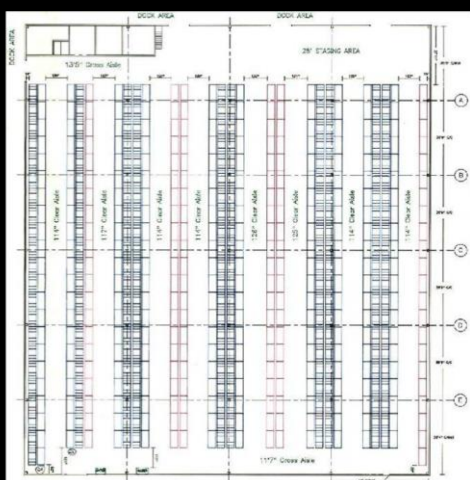
Wireless Expressways inc.

How to Cover a 40,000 square-foot Warehouse with High-Level Wi-Fi Signals Using Waveguide Technology



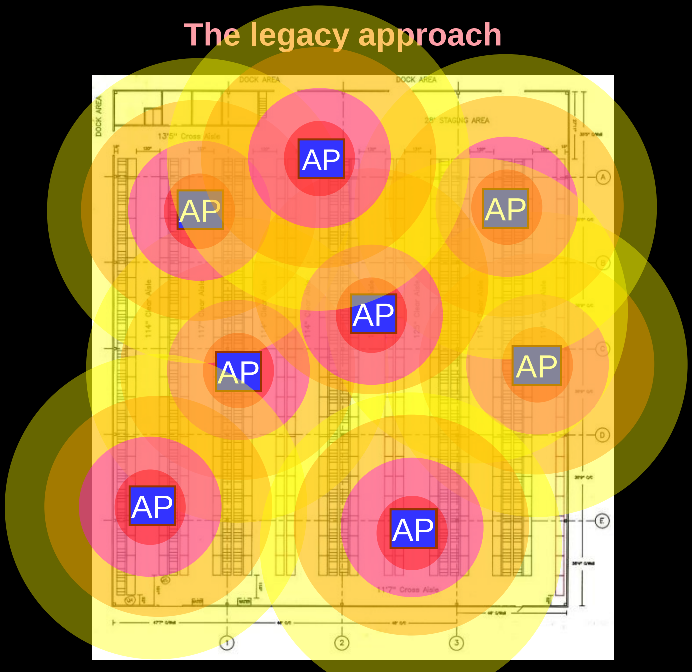
+ WE Waveguide + AP =

AP

The Legacy (wrong) Way to Design an Indoor WLAN

First, a review of how warehouse (802.11b) Wi-Fi networks have been designed in the past by "Guess and Try" site survey methods.
Here's an example of a typical legacy 8 AP system, each AP using standard omni antennas.

The legacy approach



(The signal circles are wishful thinking)

- Signals to clients are variable from day to day due to changing products on rack shelves that cause slow data and dead spots
- More than three access points cause transmission holdoffs and slower responses due to co-channel interference among APs
- Excessive roaming events can occur due to highly variable, scattered signals from multiple, access points
- Low reliability – a failure of an AP can take down an unknown zone
- Omni antennas transmit signals indiscriminately, including to locations outside buildings, causing a significant waste of AP transmitted power and a potential, serious, data security problem
- APs in a legacy system are typically mounted in the hot, dusty overhead structural iron -- not an optimal location for either the APs or those who will need to service or replace them on a lift
- Installation of multiple, scattered APs throughout a warehouse requires running a data cable to each AP. Distant APs often require fiber data feeds, long runs of conduit to supply backup power, or a local switch and UPS -- all of which are unnecessary expenses,

- WE waveguide-based systems solve these problems while lowering capital equipment costs.
- Site surveys become "sight surveys", the entire system runs faster, is more reliable, and ongoing system maintenance costs are significantly reduced.
- Any enterprise-grade access point with external antenna connectors will work with the system.

HOW OUR SYSTEM WORKS

We use an easy to configure distributed antenna technology based on WE's inexpensive, very low-loss, passive (no electronics) microwave *waveguide*.

The waveguide is used as a backbone to very efficiently transport one or more wireless signals, such as 802.11a,b,g,n,ac, to all user areas for radiation by antennas that are local to clients.

- ❖ Our new method of signal distribution allows predictable, high-quality, high speed, complete coverage in all areas of cluttered offices, malls, hotels, schools, warehouses, manufacturing facilities, and hospitals.
- ❖ Wireless security is enhanced by reducing signal leakage to outside areas.
- ❖ Reliable, high-speed wireless coverage can now be provided to all users.
- ❖ The system has been in development for over six years and is an outgrowth of a decade of implementing precursor large-scale indoor wireless networks.
- ❖ It's covered by thirty US and international patents, with more US and international patents pending.

WE Waveguide System in a Typical Warehouse

We installed an 802.11b (2.4GHz) waveguide system in a typical commercial warehouse and measured the resulting coverage and signal strengths throughout the facility

The characteristics of this warehouse at the time of the installation were:

- 40,600 square feet floor area
- Eight product aisles, nine product racks, all 175ft in length
- Height to structural iron of 24ft (~23ft to antennas)
- Racks were typically > 98% full of a wide variety of products
- Gap between products in top of racks to bottom of red iron ~4ft, typical
- 12 ft cross aisle in back of warehouse, (behind racks 2-8), was blocked with boxed metallic products stacked ~ 8ft high

Only ONE AP was needed to fully illuminate the entire warehouse. Variable couplers on the single 183 ft. waveguide backbone provided +7.4 Bm signals to each of seven high-efficiency antennas. The termination port at the end of the waveguide also provided +7. dBm to feed the antenna in aisle #8 (the last aisle), a total of eight antennas, one per aisle.

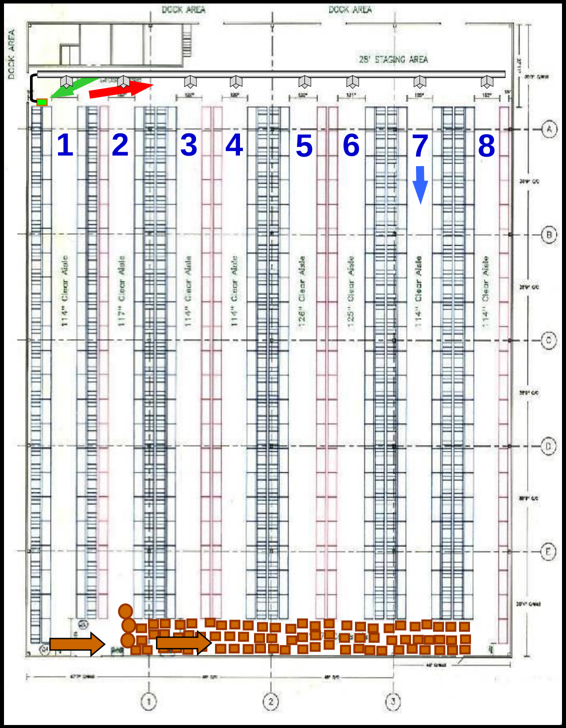
Signal strengths were recorded with AirMagnet software on a notebook computer using a Cisco CB21AG-A-K9 client card operating on 802.11b channel 6.

Views of Sections of the Test Warehouse

WE Waveguide Along Dock Cross Aisle

Single Access Point Mounted on Rack

Typical 175ft Aisle



Rear Cross Aisle

"Product Canyon" in Rear Cross Aisle

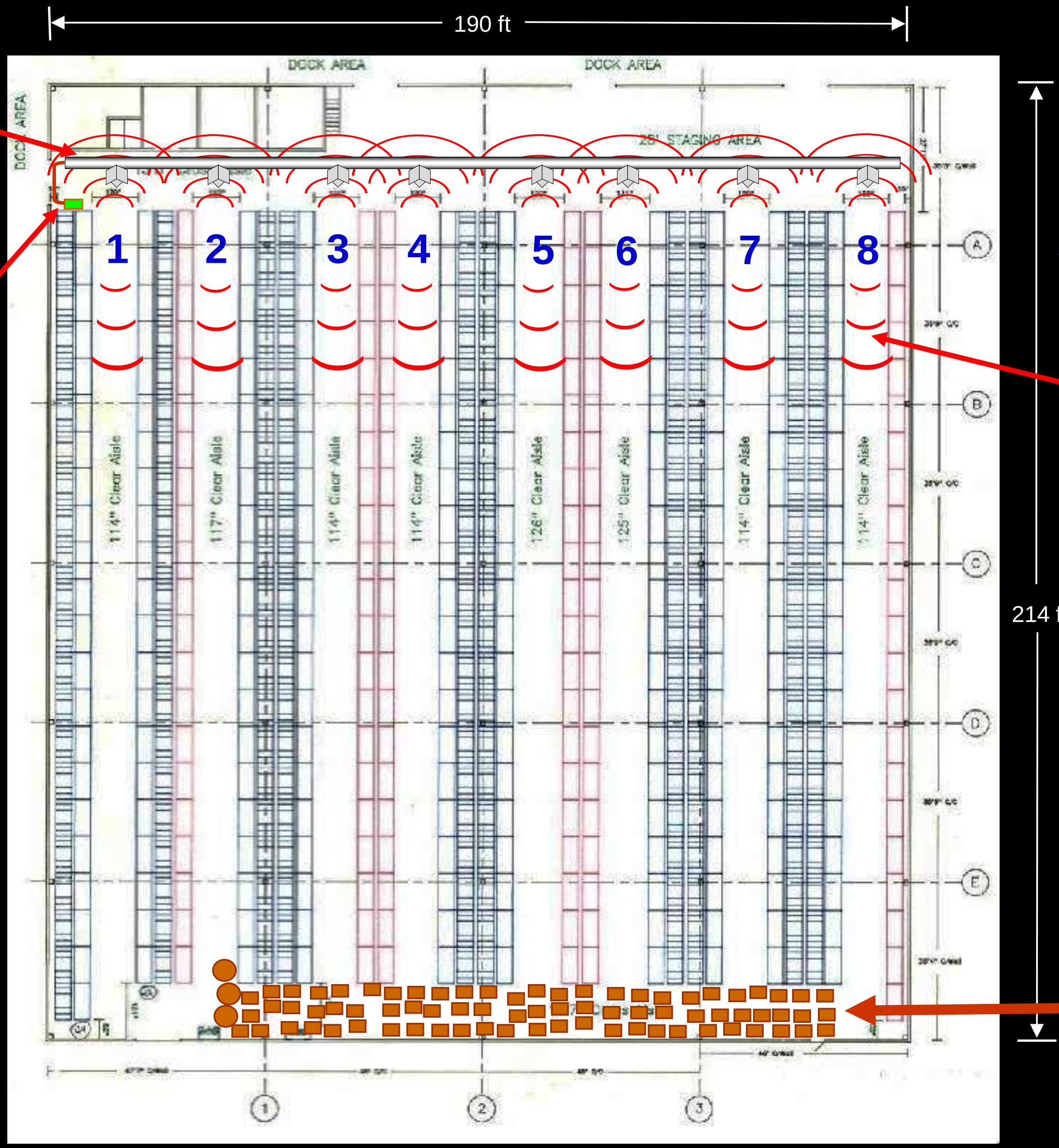
The color of each arrow on the floor plan above shows the direction viewed in each picture.

Each Aisle is Fed Separately and Equally

Waveguide and Antennas mounted below red iron fed all aisles

ONE Access Point at floor level with feed cable to Waveguide

Aisles and racks are 175ft long



Aisles

Equal signals down each aisle

8ft high stacks of metallic products stored in cross aisle

WE Waveguide System in a Warehouse

- One run of waveguide backbone is suspended from the “red iron” structure along the front cross aisle.
- Clearance is provided for other pipes, conduits, etc. under the red iron.
- Each standard waveguide section is 10ft long.
- Mechanical couplers that join waveguide sections install easily with minimal tools.
- An enclosure for the AP is mounted at floor level.
- A coax line connects the AP to the feed point of the waveguide, which can be at either end, or in the middle of the waveguide if more convenient.

- Low-loss, low-cost microwave waveguide transports signals to each aisle location.
- Variable signal couplers connect into pre-placed waveguide apertures near aisle centers.
- Directional antennas matched to warehouse aisles provide full and consistent aisle illumination.
- A Short coaxial cable connects the output of each coupler to an aisle antenna.
- “Spot beams” or other geometries of coverage can be accommodated anywhere with other antennas.
- All RF connectors are standard type “N”.

WE Waveguide-based System Is Highly Efficient

The only practical way to cover a warehouse is to direct a high-level signal down each aisle. This approach, unlike that in the legacy example shown previously, *eliminates* the need to propagate signals through products on rack shelves. An access point and antenna could be used at the end of each aisle, but that's expensive and would cause excessive co-channel interference and poor results.

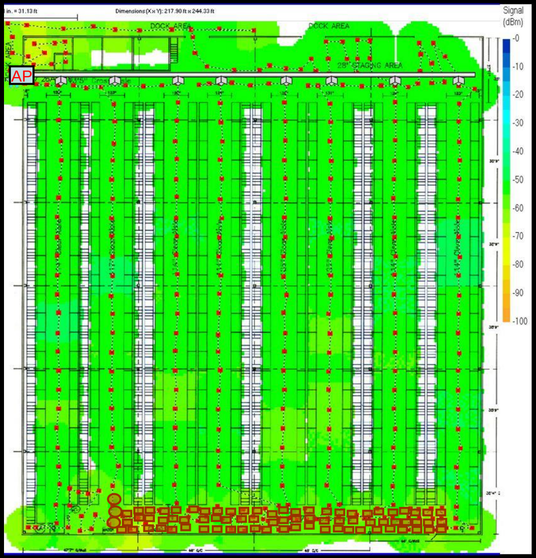
We use extremely low-loss, low-cost, microwave waveguide to deliver equal, optimum, signals from one or more access points to every aisle. Adjustable couplersin the waveguide apportion signals to aisle-optimized antennas positioned at the end of each aisle. (see signal map below)

Results of Warehouse Tests and System Features

- ONE AP easily covered the 40ksqft warehouse with high-level signals.
- Signal strengths along all aisles and front of the facility were high level and highly consistent (~ +/- 4dB throughout). (The rear cross aisle contained stacked metal products, but was still amply covered.)
- Signal patterns were optimized for minimum radiation outside the facility.

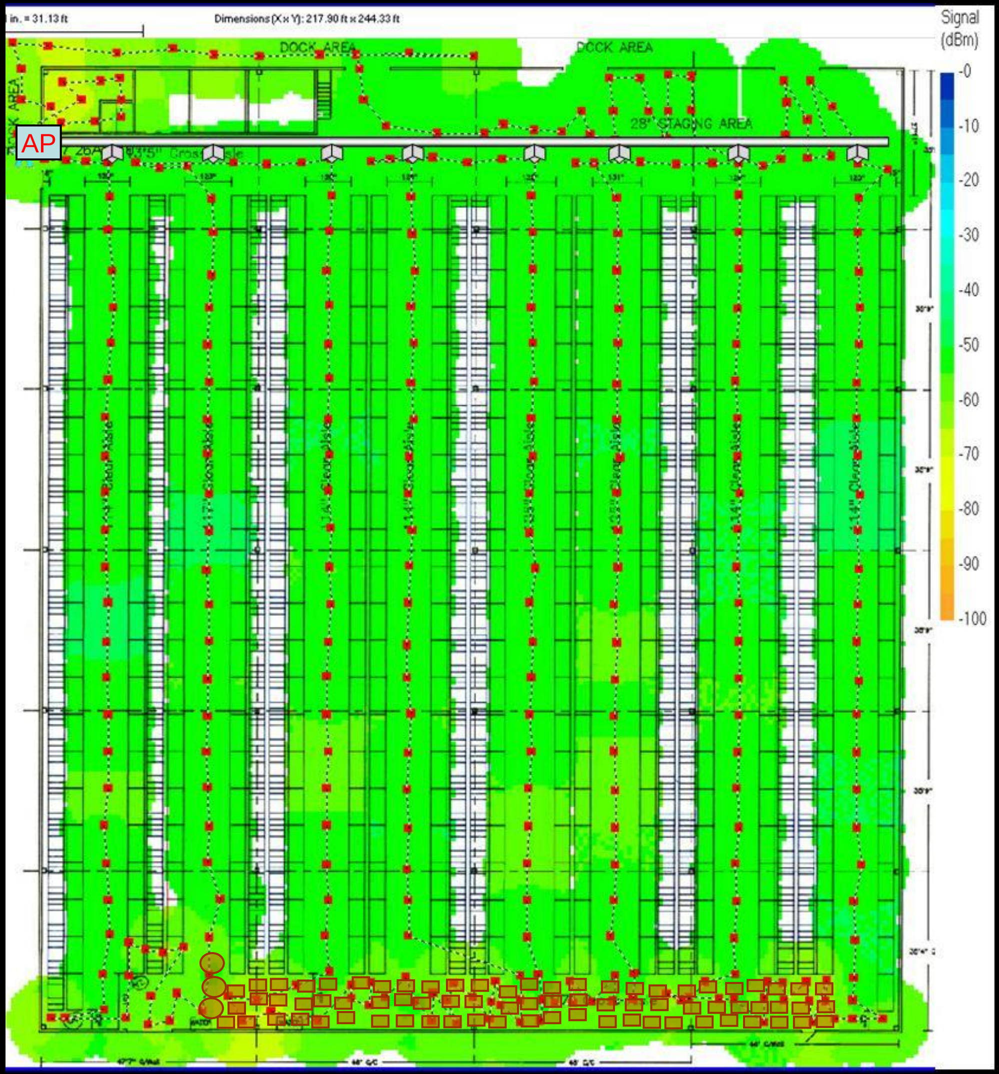
- The system is totally passive, needs ~ zero maintenance (not including access points) and can be easily modified or moved to other applications.
- Up to 3 multiplexed AP channels can occupy the same waveguide.
- APs can be mounted in an enclosure at floor level for easy access and longer equipment life
- The system is straightforward to install by communications technicians.

40.6ksqft, 8- 175ft Aisles, 9 Racks



Extensive Sampling of Signals Showed Complete High-Strength Coverage

- Over 320 signal samples were taken throughout the warehouse using Fluke AirMagnet Survey software
- The parameter measured was AP signal strength in dBm.
- All readings were taken with a notebook PC using a Cisco CB21AG-A-K9 Wi-Fi card whose antenna was at ~ 42 inches from the floor during all readings.
- Signals on the external dock were recorded to show dock signal coverage
- Some areas were left blank without samples due to inaccessibility caused by products stacked in those areas
- The radius of equal levels in each of these signal recordings is ~4 feet
- Rack spaces that appear to have no signals are artifacts of the way each measurement is displayed; although signal levels inside racks are high, they are of little or no concern
- Stacked metallic objects in boxes in the rear of the warehouse partially blocked signals, but signals survived with sufficient threshold for full speed.



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Detailed Signal Levels at ~ 8ft. Intervals Throughout the Facility

Coverage Data in 40k Warehouse

A Cisco 1240 access point was connected to the waveguide system through a coaxial feed cable. The AP was set at +17dBm xmit level. Input to the waveguide feed point was +15.3dBm due to feed line loss.

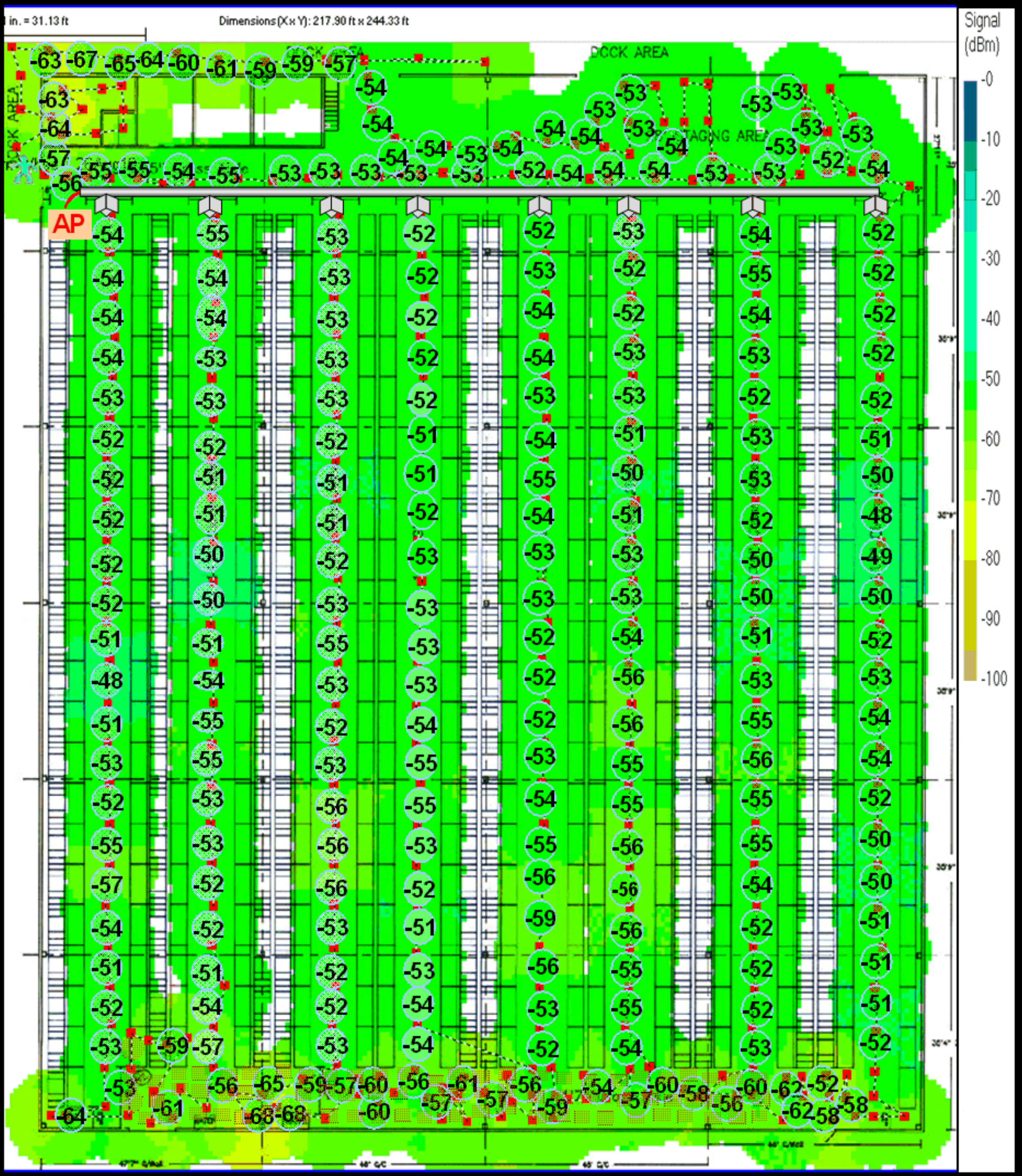
We measured the 802.11b signal levels at all accessible client areas in the warehouse while feeding the waveguide with ONE access point radio mounted at ground level.

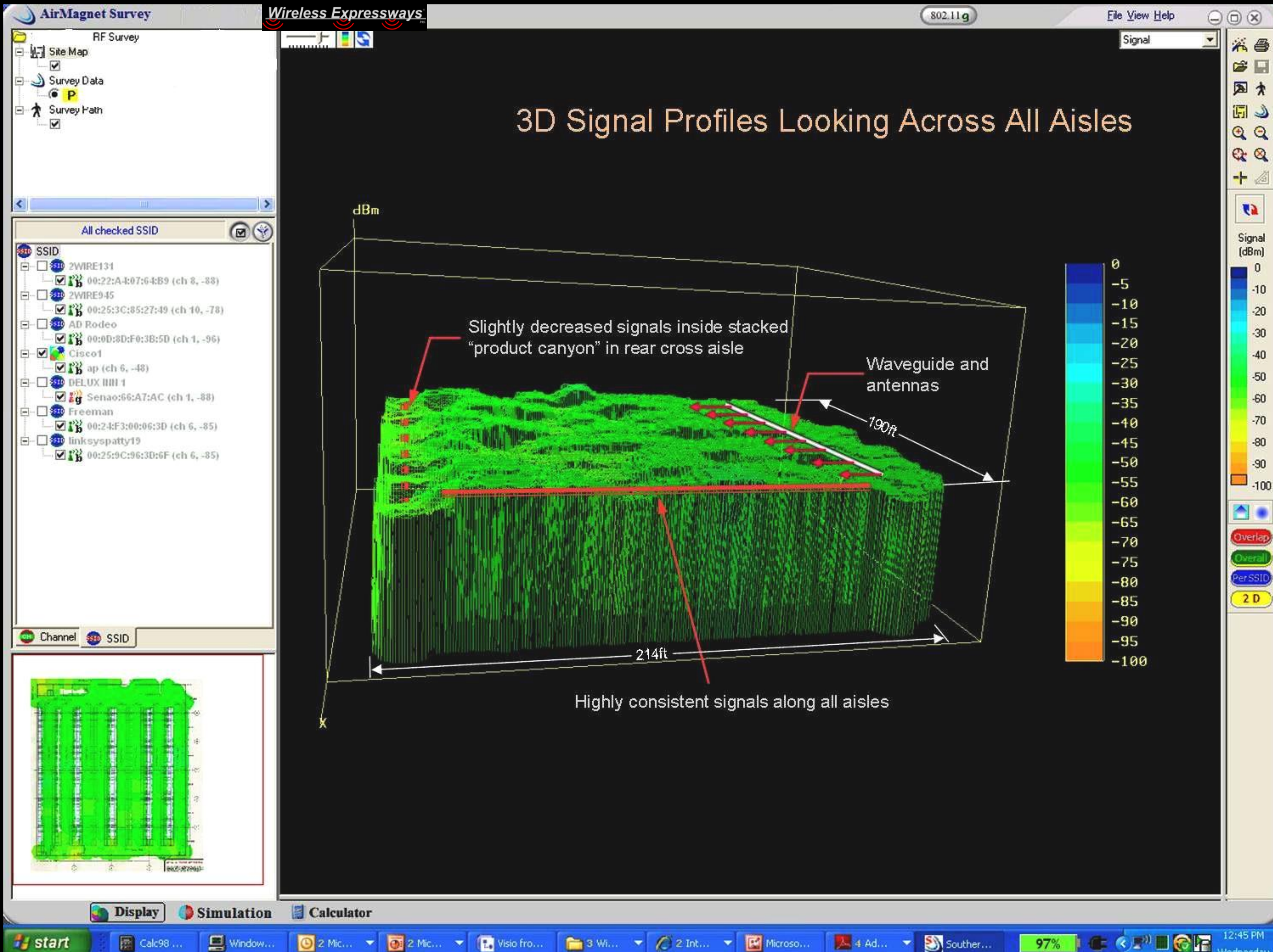
NOTE THE CONSISTENT SIGNAL LEVELS

RESULTS

The tests clearly show that the system provides complete, high-level coverage in all locations, even in the “canyon” of products at the rear of the warehouse. The receive level at any location was at least 20-35dB above receiver threshold (- 88dBm), an exceedingly high signal margin.

The data confirms that many variations in highly efficient system topologies may be easily configured using our waveguide approach.





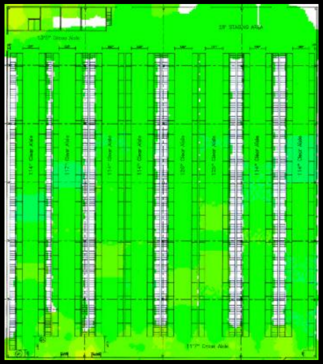
AirMagnet Survey
Wireless Expressways
802.11g
File View Help
RF Survey
Site Map
Survey Data
Survey Path
All checked SSID
SSID
2WIRE131
00:22:A4:07:64:B9 (ch 8, -88)
2WIRE945
00:25:3C:85:27:49 (ch 10, -78)
AD Rodeo
00:0D:8D:F0:3B:5D (ch 1, -96)
Cisco1
ap (ch 6, -48)
Freeman
00:24:F3:00:06:3D (ch 6, -85)
linksyspatty19
00:25:9C:96:3D:6F (ch 6, -85)
Channel
SSID
Signal
3D Signal Profiles Looking Across All Aisles
dBm
Slightly decreased signals inside stacked “product canyon” in rear cross aisle
Waveguide and antennas
190ft
214ft
Highly consistent signals along all aisles
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
Signal (dBm)
Overlap
Overall
Per SSID
2 D
Display
Simulation
Calculator
start
12:45 PM
Wednesday

Projected Configurations Based on Field Test Data

Client loading is normally not a factor in a warehouse Wi-Fi system since devices, such as handheld bar code scanners, burst short messages from clients using 11Mbps 802.11b,g. Additional applications, e.g. VOIP phones and devices that require higher signal availability or speed can be added to the same waveguide backbone on 1 or 2 *separate* channels at minimal cost. Channels 1, 6, and 11 may be combined on a waveguide and will be equally propagated to ALL client areas. The additional channel(s) can also be used for backup. Other configurations can be extrapolated from the test data.

Using the documented 40.6ksqft warehouse as a basis for iteration:

NOTE: All of the following calculations are at 2.4GHz.
Systems at 5GHz will have about 8 dB lower margins.



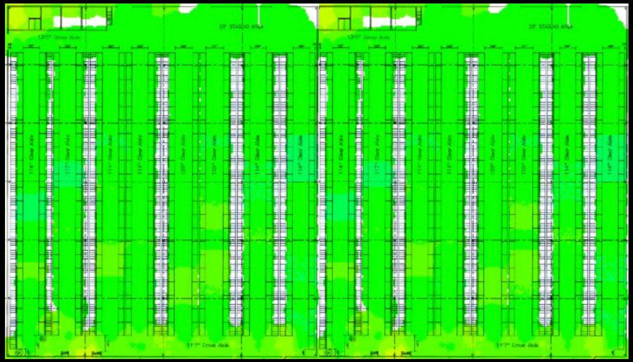
Add a **Second AP** to the waveguide on a second channel for redundancy or a separate application, e.g. VOIP phones

Reduces receive margin by: 2dB
Remaining margin: 18-33dB

Both channels appear equally everywhere. This option can be easily added to a basic one-channel WE system.

Note: Higher margins are for 802.11g
Lower margins are for 802.11b

Cover **2 warehouses** using **1 AP**



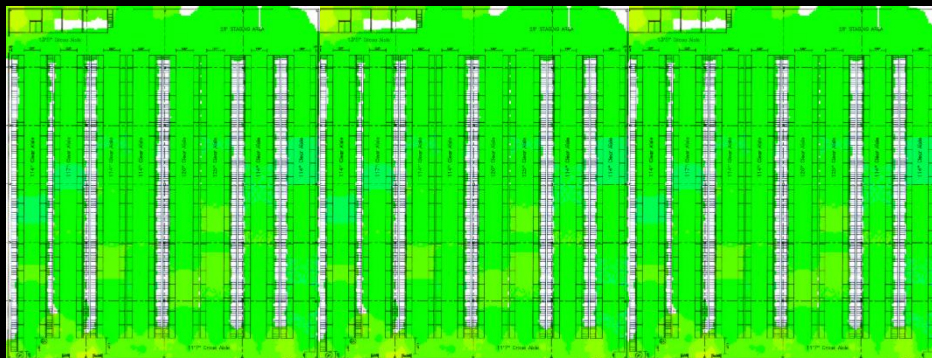
Total coverage area: **81ksqft**

Reduces receive margin by: 5dB to each warehouse

Remaining margin: 15-30dB

Projected Configurations Based on Field Test Data …cont.

Cover **3 warehouses** using **2 APs,** both of which appear in all **122ksqft**

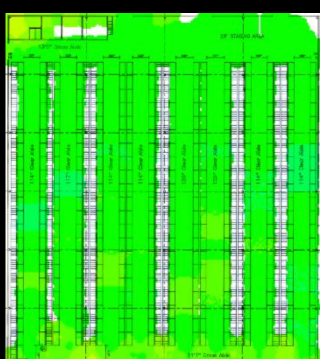


Total coverage area: **122ksqft**

Both APs appear everywhere.

Reduces receive margin by: 9dB
Remaining margin: 11-26dB

Cover **1 warehouse with low client transmit power**



If the rear cross aisle was clear of obstructions, this entire warehouse could be covered with **all client devices running 5mW transmit** level, enabling an increase in client battery lifetime before recharge. Signal receive margin would be ~10 dB at the AP.

Notes: tandem waveguides may be connected through intervening walls with a signal loss of ~ 1dB per interconnect between them.

Special areas, such as dock offices, coolers, etc., may be covered with narrow beamwidth antennas placed at the waveguide or carried over coaxial extension cables to the area to be covered.

The main waveguide may be fed from either end or the middle. One or more waveguide branches may be attached to the main waveguide to service special areas.

Summary

- The guesswork is taken out of wireless network design and deployment -- our systems are accurately *engineered* to fit each user environment
- Signals are "taken to the user" over a very high efficiency, low-loss (0.8dB/100ft @ 2.4GHz) waveguide backbone that, in effect, "short circuits" free-space and clutter loss
- Signal levels to each antenna are adjustable over a 40dB range by variable signal couplers along the waveguide ports that provide precise, *prescribed* user area illumination levels
- Antenna pattern, gain, and signal power are matched to the requirement in each client area
- Far fewer access points, port switches, AP controllers, wiring, software licenses, etc., are needed to implement high-quality large-area indoor systems
- Roaming among access points by clients attempting to establish a suitable link is virtually eliminated since high-quality signals are available in all client areas
- Signal levels outside the facility are reduced in the design of each system. This improves data security by limiting radiation into external areas and reducing incoming interference to APs in the warehouse from external sources
- Co-channel interference among access points inside a facility is virtually eliminated, allowing maximum client access , data throughput, and channel reuse in larger buildings.
- Highest data rates and minimum transmission delays are provided everywhere
- The system described here is also very applicable to IIoT manufacturing sites
- Although 2.4GHz was used throughout this report, all concepts also apply to 5GHz systems

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