How to Properly Design an In-Building Distributed Antenna System (DAS).

RF in-building coverage has become a fast growing market in recent years. Commercial wireless users increasingly demand reliable communications inside office and residential buildings for their business and personal needs. At the same time, various local municipalities have issued ordinances to ensure that construction of new buildings include adequate radio coverage of public safety signals. Efforts are also underway to develop and implement national level model codes for public safety in-building communications, as seen by recent initiatives at National Fire Protection Association (NFPA) and the International Code Council (ICC).

A typical in-building coverage system consists of two major components, a bi-directional amplifier (BDA, or signal booster) relaying and amplifying the RF signal traffic between the remote base station and the portable or mobile radios, and a network to distribute the signal to every corner of the desired coverage area. The most common type of the distribution network is a system of coax cables and indoor antennas called a Distributed Antenna System or DAS.

Most of the reference materials and application notes on in-building coverage solutions have focused on the booster technologies or system design architecture. One often overlooked aspect in the system design is the DAS implementation. This includes connecting all the cables and antennas throughout the building and balancing the signal levels at each DAS node.
If ignored, an improperly designed DAS results in degraded performance and unnecessary cost increases. This 2-part series of articles is an effort to outline a simple process of designing a DAS in order to achieve the most efficient RF coverage distribution. Part I talks about the Use of Directional Couplers in DAS and Part II covers the DAS Design Process.

Part II. The DAS Design Process

The first step of DAS design is to obtain an accurate and up-to-date blueprint of the building. An architectural drawing is best, but even a fire exit map will suffice, as long as it's drawn to scale. Be careful when using the scale on any drawing to calculate the real dimensions; the piece of paper sitting on your desk may not be the same size of the paper when the drawing was originally made. If it has been shrunk to fit your 8.5x11" printer paper, the "1in = 10ft" scale printed on the drawing is no longer valid. When in doubt, it is always a good idea to double check. Known building dimensions or square footage are also good references. Another simple rule of thumb is to check the opening of a regular single door, which has to have a 36-inch clearance as specified by ADA. Therefore, when everything else fails, you can always calculate the scale by measuring width of a door on the drawing.

The second step is to make sure you know all the relevant physical information related to the building and the DAS installation. What kind of material was used for exterior construction? Could some RF signals be present on upper floors and near exterior boundaries that will reduce the need for the in-building coverage? What kind of material was used for interior construction, drywall or concrete? Is the building designed for a special application that may result in RF blockage? Many hospitals and power generating plants fall into this category. Are there any restrictions on the cable runs and antennas installation? Some buildings won't allow any visible hardware for aesthetic reasons. Where can the cables go between floors? Where will the head-end booster be located? Answers to these questions will have a great impact on the coverage area for each DAS node, hence dictating where and how the DAS should be installed.

A quick word on another type of DAS: radiating cable. It is essentially a coax cable with lots of tiny slits cut along the length of the cable. Each slit functions as a tiny antenna with RF energy leaking out of it, hence the nickname "leaky cable". The signal levels coming out of the radiating cable are pretty low, so the coverage area is typically no more than 20 or 30 ft on

either side of the cable. Therefore, it's better suited for areas that are long and narrow such as tunnels or long hallways. Because of the fact that signals are coming out of the cables throughout, the insertion loss of the cable is typically higher than comparable coax and it's something to keep in mind during the DAS design. For the rest of this article, I will focus on the coax and antenna type of DAS, but the layout of a radiating cable DAS can use the same design guidelines.

With a scaled building blueprint in hand and a good understanding of the particular limitations of the project, the designer can now sit down and map out all the DAS nodes, i.e. locations of the antennas. Typically, an omni-directional indoor antenna with 0 dBd of gain can adequately cover an area with a 100~150 ft radius at 800 MHz, a 200~250 ft radius at UHF, and a 300~400 ft radius at VHF. These numbers are derived from link budgets based on the free space loss at those frequencies and the typical power level put out by the signal booster. Obviously, the designer has to exercise his or her judgment to account for the unique circumstances of the project. The same antenna, at the same frequency, will have very different coverage on an open office floor with cubicles versus coverage on a dormitory with many small rooms separated by concrete walls.

After the location for each antenna node is picked out, the designer "connects the dots," with the lines representing cables in real life. We can measure the length of the cable on paper, and then use the scale to calculate the cable length. The insertion loss for the cable is calculated based on specifications provided by the manufacturer. So, at this point, we know the location and loss of each cable run. See Figure 6 for a simplified drawing of one floor in a building, with two antenna nodes. It's assumed that this DAS covers multiple levels in the building, so there is a vertical cable run that connects each floor. Therefore, we have two antennas on the floor, one cable split for those 2 antennas, and another cable split for the vertical cable run.
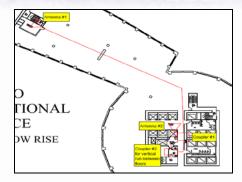

Figure 6. An Example of One Floor in a Building DAS

In order to make it easier to see, a DAS design is often drawn up with 2 sets of diagrams, one with direct marking on the building blueprint to indicate the location of the antennas and cable splits, and a second set of "abstract" drawings (typically in Visio[TM] or Autocad[TM]) showing the cable lengths and coupler models. Figure 7 shows the "abstract" version of the drawing for the same DAS in Figure 6.
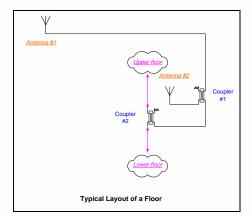

Figure 7. Abstract DAS Drawing

Here comes the important part of DAS design: how do you connect all the cable segments and antennas to make them into a network? As discussed in Part I of this article, directional couplers are much better alternatives than splitters at this task. They offer various power split ratios to allow the designer flexibility in balancing the power level at each DAS node.

The main goal of using couplers is to offset the difference in cable losses by using the different loss ratios between the two outputs of the coupler. For example, if a cable run is split into two branches, say

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15 dB IL in one branch vs. 5 dB IL in the other, we would like to select a coupler that has 10 dB of difference in power split ratios. Put the lower loss port on the higher loss branch, and the higher loss port on the lower loss branch, and Presto: we have two branches with same amount of total losses (including the coupler and the cable). Most manufacturers of directional couplers provide a series of products with different split ratios to allow the designer to match the loss differentials as closely as possible.
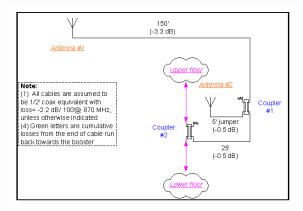

Figure 8. DAS with Cable Losses

Back to the example we were looking at. In Figure 8, we have a branch with 150 ft of cable with about 3.3 dB of insertion loss, and another branch of 3 ft jumper cable with 0.5 dB of loss. We need to select a coupler that can make up the loss differential in the two cable runs. Browsing through the table of available couplers in a catalog, we select a coupler model number with a 4.8/1.8 dB split ratio as Coupler #1. If we connect the longer cable run to the throughput port with 1.8 dB, and connect the shorter cable run to the coupled port with 4.8 dB, the total losses from the input of the coupler to the antennas are 3.3 + 1.8 = 5.1 dB and 0.5 + 4.8 = 5.3 dB respectively. If we had used a 3 dB splitter, the total losses would have been 3.3 + 3 = 6.3 dB and 0.5 + 3 = 3.5 dB. Right away, one can see the benefit of using a coupler as it manages to balance the signal levels at the two antennas within 0.2 dB of each other.

Next, we work our way backwards toward the booster. We take the worse number of the two above (5.1 and 5.3 dB, so we use 5.3 dB), and add the 0.5 dB cable loss between the two couplers, we get 5.8 dB, which

is the loss from the output of Coupler #2 to either Antenna #1 or Antenna #2. See Figure 9 for the illustration of calculating the cumulative loss.
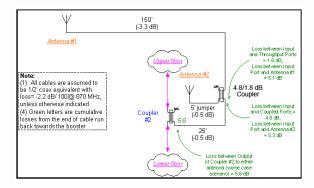

Figure 9. Calculation of Cumulative Loss in DAS

Now, let's assume there are more floors above this one. The DAS on the upper floor has been balanced using couplers in the same way as illustrated, and the total loss in the DAS on the upper floor has been calculated to be 10 dB. See Figure 10 as we "propagate" the loss in the DAS backwards toward the booster.
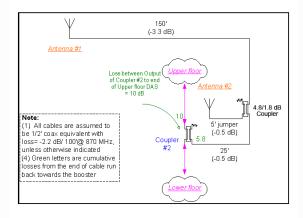

Figure 10. Calculation of More Cumulative DAS Loss

Again, we want to select a coupler that will offset the loss differential and balance the signal levels. Browsing through the coupler catalog, we find a coupler with a 6/1.2 dB split ratio. If we connect the 6 dB coupled port to the lower loss DAS on this floor, and the 1.2 dB throughput port to the higher loss DAS on the upper floor, we get 5.8 + 6 = 11.8 dB and 10 + 1.2 = 11.2 dB. Therefore, the total losses from the input of Coupler #2 to the cable runs on this floor and

the cable runs on the upper floor are within 0.6 dB of each other. See Figure 11 for a total tally of all the losses.
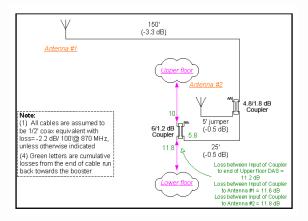

Figure 11. Completed DAS Design for One Floor

If there are more floors below it or more cable splits between this one and the booster, the same iteration is to be repeated until we work all the way back to the booster. A typical in-building coverage system can vary from 10,000 sq ft to 1,000,000 sq ft or more, with the number of couplers from a handful to hundreds. However, the rules of calculating the losses and selecting the couplers stay the same, allowing the designer to balance any DAS and achieve the optimal signal levels throughout the network.

As mentioned before, the total DAS loss should be limited to no more than 25~30 dB, in order to maintain a sufficient signal to noise ratio. As we start calculating the loss and selecting couplers from the remote end of the DAS and work backwards toward the booster, we eventually get to a point that the system loss exceeds the limit. We know that we will need to insert an in-line booster at that point. The exact location is of course dependent on the practical constraints of the building, but wherever the in-line booster is, the cumulative loss ends at its output, and starts from zero again on the other side of the in-line booster. Another alternative is to use coax with larger diameters with lower insertion loss. But that option carries its own disadvantages such as high material and labor costs, as well as the physical limitations on bending radius and weight support issues.

In summary, DAS design is a combination of node placement and simple mathematics. Couplers and coax cables do not have the glamour or complexity of the signal booster. However, a little attention to these often overlooked components in the DAS goes a long way to ensure that the performance of the system lives up to the design specification and, more importantly, to the expectation of the customer.