

How to Properly Design an In-Building DAS

Part I Use of Directional Couplers in DAS

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 I: Use of Directional Couplers in DAS

When facing the question of cable connections in a DAS, many designers or installers choose the easy answer of using standard two-way splitters for every cable and antenna junction. The splitters are relatively inexpensive, and there is no thinking required. However, except for the simplest systems with very small coverage area and few antennas, the use of splitters will have a seriously negative impact on the system performance.

Let's look at an example. It's a very simple DAS with five antennas. All cable splits and antenna junctions are connected with two-way splitters. Each splitter provides a 50%-50% split of the power, which translates to a 3 dB insertion loss between the input port and the two output ports. The splitters are bi-directional, so when two signals are combined through the splitter going the other way, there is also a 3 dB insertion loss.

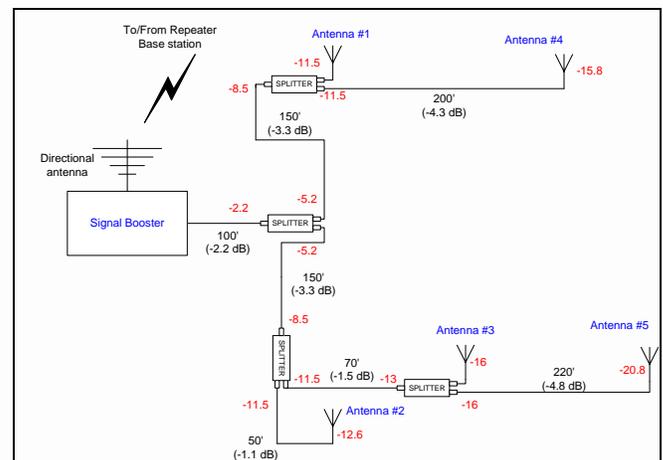


Figure 1. A Simple DAS Using Only Splitters

The red numbers shown in Figure 1 are cumulative losses, expressed in dB, in reference to the output of the Signal Booster. If we assume the signal coming out of the booster is at 0 dBm, then the numbers can be viewed as signal levels at each junction expressed in dBm. It is obvious that the signal levels at the antennas vary quite a bit. The signal levels at Antennas #1 and #2, which are nearest to the



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booster, are -11.5 and -12.6 dBm, while the signal level at Antenna #5, farthest away from the booster, is -20.8 dBm. There is more than 9 dB of difference between the near and far antennas. Increased size of the DAS and the number of cable splits this “near/far” problem is even more serious. In a more typical DAS, instead of a simplified example as shown above, it is not uncommon to see signal level differentials of more than 20 or 30 dB!

Such a scenario can lead to severe degradation of the in-building coverage. When antenna nodes in the DAS have equalized losses, the most uniform coverage is achieved, i.e. portables anywhere in the coverage area “sound” the same. Whereas, such disparate signal levels can lead to uneven and diminished coverage both in area size and in audio quality. In extreme cases, calls may even be dropped. Imagine two users in the building: one is positioned at Antenna #1 while the other is at Antenna #5. They simultaneously key up their radios and try to talk back to the central station. If they both use the same radios and are transmitting at the same power level, the signal received from the user at Antenna #1 is simply 9 dB stronger than the one at Antenna #5. If the user at Antenna #1 happens to use a higher power radio, for instance a mobile instead of a portable, his strong signal may activate the Output Level Control in the booster, which is a mechanism used by the signal booster to adjust the gain and output power per carrier based on the strength of the incoming signals. (All boosters have to be equipped with OLC in order to comply with FCC regulation to reduce undesired spurious emissions.) Once the OLC is engaged, it reduces the overall gain of the booster, which further weakens the signal from Antenna #5. Therefore the difference in signal levels between the two incoming signals increases, and the user with the weaker signal will, most likely, not be able to complete his call.

Additionally, to maintain a sufficient signal to noise ratio, the loss in any DAS should be limited to within 25–30 dB. In expanding the example above, there is another hallway beyond Antenna #5 that requires coverage. It needs more cables and splitters so; the loss on that branch will easily go beyond the 25 dB limit. In-line boosters will need to be deployed to amplify the signals when loss exceeds that limit.

Since the signal levels at Antennas #1 and #2 are unnecessarily high, it would be more efficient if we could divert some of the RF energy away from Antennas #1 and #2 and send them toward #5. In other words, as the signal comes out of the booster, what if we provide only a small portion of the signal to the shorter branches, but preserve the majority of the RF energy for the long run toward Antenna #5? We can accomplish that with Directional Couplers.

A 2-way splitter is a simple 3-port device, forming a physical and a functional “Y”, a Directional Coupler is typically a 4-port device.

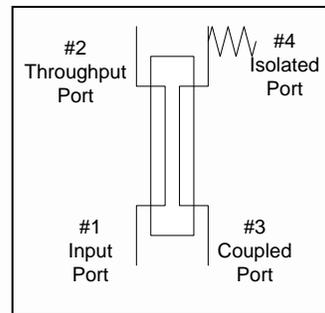


Figure 2. Ex of a Typical Directional Coupler Schematic

As shown in Figure 2 above, the four ports on the coupler have different designations depending on the signal path. When used in a DAS, one of the ports will have a load connected to it. The use of this port will become evident shortly when we discuss the bi-directional nature of the coupler. When a signal enters the coupler from the #1 Input Port, part of it comes out from the #2 Throughput Port (sometimes called ThruLine Port) and another part of the signal comes out from the #3 Coupled Port (sometimes called Decoupled Port). The ratio between the signals is commonly referred to as the “coupling ratio” and is usually noted in dB. If the ratio is 3/3 dB, then the two signals are split 1:1 evenly and each output is 3dB lower than the input signal. But the coupler can also be constructed to have uneven split ratio. Let’s look at an example of a 4.8/1.8 dB coupler, which has a 1:2 split ratio, or in other words, 33/66% of the input signal.



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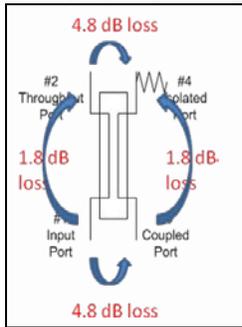


Figure 3. A 4.8/1.8 dB Coupler

As shown in Figure 3, compared to the input signal, the output at the Throughput Port is 1.8 dB lower than the input signal, while the output at the Coupled Port is 4.8 dB lower.

However, the designations of the ports are not fixed since the coupler itself is symmetrical. In reality, a RF signal can enter any port. Whichever port you select as the Input, the other port on the same side becomes the Throughput Port, while the port opposite side from the input becomes the Coupled Port. As shown in Figure 4, if the signal is now coming in from Port 2, which is now designated as the Input Port, then we simply have a whole new set of port designations noted in red.

Please notice that nothing has changed physically between Figure 3 and Figure 4. The load is still on Port #4. The only change is in the reference point or the perspective of the “input” port. Remember the signal booster and DAS are bi-directional by nature, so another way to look at these two figures is that the coupler in Figures 3 and 4 is seen from the perspectives of opposite signal paths (uplink and downlink). In Figure 3, it’s the downlink signal that goes from the booster out to the DAS antenna node. In Figure 4, the signal from the portable radio is picked up by the in-building antenna and is going back toward the booster. In the case of Figure 4, the signal entering Port #2 will have 1.8 dB loss when coming out of Port #1.

Another signal at -4.8 dB will go toward Port #4 where the energy is absorbed by the load. Similarly, another uplink signal from the portable radio back toward the booster enters the booster from Port #3 (marked as the Coupled Port in Figure 3). It loses 4.8 dB and comes out of Port #1 as well.

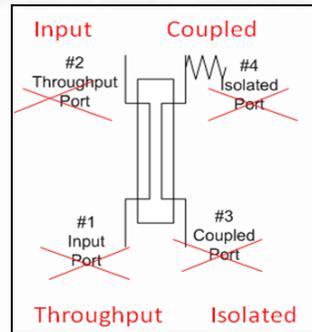


Figure 4. The Same 4.8/1.8 Coupler with Signal Coming In From Port #2

Some of that signal goes to Port #4 at -1.8 dB and is also absorbed by the load. Hence, the signal paths between Ports #1 and #2, and Ports #1 and #3 have the same loss in both directions. Such bi-directionality and fixed loss ratio between ports ensure the DAS can be balanced simultaneously for uplink and downlink signals.

Because of this bi-directionality, it’s crucial to make the correct port connections during installation. A reversed connection will not be immediately obvious, as the signals will still come through, albeit with very different losses as the designer had intended. It is not unusual for a DAS system to fail the coverage acceptance test even though the design has plenty of margin built-in. The painstaking trouble-shooting process would eventually lead to one or several couplers with reversed cable connections. A simple yet effective way to ensure that the right cable is going with the right coupler port is to have the field technicians hold the coupler with the load oriented in the same way as shown on the schematic. Then the rest of the ports simply fall into place by matching the various cable segments on the DAS layout drawing.

An additional advantage of the coupler over the splitter is the isolation between two ports at the opposite corners (Ports #1 and #4, Ports #2 and #3). Such isolation becomes instrumental in other applications of the directional coupler, such as in a transmit combiner. However, that is not the focus of this white paper.

Beyond the 3/3 dB and 4.8/1.8 dB ratios, couplers can be made to have coupling ratios of 6.0/1.2 dB (25/75%), 7.0/1.0 dB (20/80%), and all the way to 30/0.1 dB (0.1/99.9%). Typically, a manufacturer will



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offer a series of couplers with varying split ratios for an entire frequency band. Some manufacturers even take advantage of the nature of multiple harmonics and offer couplers that cover VHF, UHF, and 800 MHz frequencies simultaneously. Table shows the “TXRX Systems” brand coupler portfolio offered Bird Technologies Group.

Model Number	Frequency Band (MHz)	Coupled / Through port Loss	Split Ratio in %
Multi-band Harmonic couplers			
85-05-01	144-174/450-530/806-890	3.0/3.0 dB	50/50%
85-05-02	144-174/450-530/806-890	4.8/1.8 dB	33/66%
85-05-03	144-174/450-530/806-890	6.0/1.2 dB	25/75%
85-05-04	144-174/450-530/806-890	7.0/1.0 dB	20/80%
85-05-05	144-174/450-530/806-890	10/0.5 dB	10/90%
85-05-06	144-174/450-530/806-890	15/0.2 dB	3/97%
85-05-07	144-174/450-530/806-890	20/0.1 dB	1/99%
VHF couplers			
85-38-01	132-174	3.0/3.0 dB	50/50%
85-38-02	132-174	4.8/1.8 dB	33/66%
85-38-03	132-174	6.0/1.2 dB	25/75%
85-38-04	132-174	7.0/1.0 dB	20/80%
85-38-05	132-174	10/0.5 dB	10/90%
UHF couplers			
85-58-01	350-512	3.0/3.0 dB	50/50%
85-58-02	350-512	4.8/1.8 dB	33/66%
85-58-03	350-512	6.0/1.2 dB	25/75%
85-58-04	350-512	7.0/1.0 dB	20/80%
85-58-05	350-512	10/0.5 dB	10/90%
85-58-06	350-512	15/0.2 dB	3/97%
85-58-07	350-512	20/0.1 dB	1/99%
85-58-08	350-512	30/0.1 dB	0.1/99.9%
700/800/900MHz couplers			
85-83-01	746-960	3.0/3.0 dB	50/50%
85-83-02	746-960	4.8/1.8 dB	33/66%
85-83-03	746-960	6.0/1.2 dB	25/75%
85-83-04	746-960	7.0/1.0 dB	20/80%
85-83-05	746-960	10/0.5 dB	10/90%
85-83-06	746-960	15/0.2 dB	3/97%
85-83-07	746-960	20/0.1 dB	1/99%
85-83-08	746-960	30/0.1 dB	0.1/99.9%

Table 1: Directional Couplers

Now, let's take another look at the earlier using directional Couplers instead of splitters.

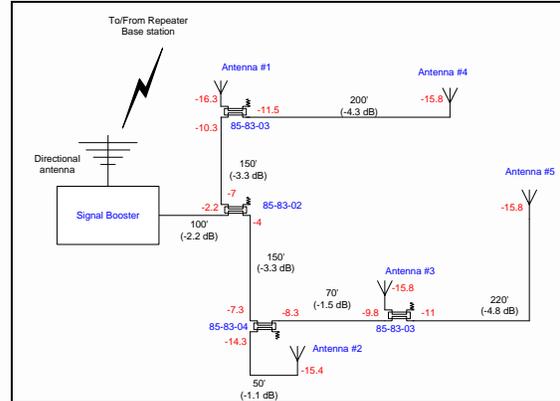


Figure 5. A Simple DAS Using Directional Couplers

With directional couplers, every antenna's signal level is now within 1 dB of each other. We don't need to worry about the “near-far” problem anymore. Nor do we have to spend additional money to install an in-line booster, since the loss of 15.8 dB at Antenna #5 is far below our threshold of 25~30 dB. Therefore, the judicious use of directional couplers greatly improved the system performance by balancing the DAS loss at each antenna node, and reduced the hardware cost by eliminating the need for an in-line booster.

In summary, while the choices of signal boosters and antennas are often the focus of the designer and the user of an in-building coverage system, the directional couplers are equally critical in their contribution to the successful implementation of the DAS.

If you are wondering how to select the correct couplers with the correct split ratios to end up with the balanced signal levels as shown, please see Part II of this article. We will provide a step by step instruction on the DAS design, including how to calculate cumulative losses and how to choose directional couplers in order to balance the signal levels.



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