CONTINUOUS COVERAGE

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Cell Extender Antenna System Design Guide Lines

1. General

The design of an Antenna system for a Cell Extender site needs to take into account the following specific factors:

a) The systems input and output frequencies can be relatively close.

b) The Cell (output) channels are fixed, but the Donor (RF Link) radios are frequency agile, as the channel can vary from call to call (to follow the Donor sites Traffic Channel allocation).

This Document is specially written to assist in Cell Extender antenna system design. As such, it is assumed that the reader has a good understanding of standard antenna system design techniques such as filter, multi coupler and other combiner technologies, as issues discussed in this Document only relate to specific Cell Extender application aspects. Matters such as elimination of Intermod products etc are not addressed in the context of this Document - please refer to normal common standard techniques and practices for these issues.

Please note that this Document provides design "Rules" only. Experience in antenna system design remains indispensable in actual practice!

2. Frequency Separation - Cell Site MPT Channel Selection

In any Cell Extender system the Cell radio Tx and Donor radio Rx frequencies (and conversely, Cell Rx and Donor Tx frequencies) will usually be in the same segment of the frequency band.

For example, assume that the Donor Site Base Stations transmit "High" and receive "Low". The Cell Extender Donor radios will now be transmitting "Low" and receiving "High". However, like the original Donor Site, the Cell Extender Cell Site Base radios will again transmit "High", and receive "Low". So, the Cell Extender input and output frequencies operate in the same part of the frequency band and hence, the frequency spacing between the various transmitter and receiver frequencies can be much closer than in a normal duplex situation.

For this reason care must be taken with the selection of the Cell Control and Traffic channels, so as to achieve the largest possible spacing between Cell Tx and Donor Rx frequencies (and conversely, between Donor Rx and Cell Tx frequencies)

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Example:

In a 25 kHz channel spacing system the Donor Site MPT Channels are:

DONOR SITE CHANNELS

	MPT Ch. No.	Tx Frequency	Rx Frequency
Control Channel:	**Ch 100**	**350.000 MHz**	**360.000 MHz**
Traffic Channels:	**Ch 120**	**350.500 MHz**	**360.500 MHz**
	Ch 140	**351.000 MHz**	**361.000 MHz**

Since the Cell Extender Donor Radios operate on the reverse frequencies, the Cell Extender Donor radio frequencies will be reversed:

CELL EXTENDER DONOR RADIOS

	MPT Ch. No.	Tx Frequency	Rx Frequency
Control Channel:	**Ch 100**	**360.000 MHz**	**350.000 MHz**
Traffic Channels:	**Ch 120**	**360.500 MHz**	**350.500 MHz**
	Ch 140	**361.000 MHz**	**351.000 MHz**

Assume now that the Cell Channels were chosen as MPT channels 130 and 121:

CELL EXTENDER CELL RADIOS

	MPT Ch. No.	Tx Frequency	Rx Frequency
Control Channel:	**Ch 130**	**350.750 MHz**	**360.750 MHz**
Traffic Channel:	**Ch 121**	**350.525 MHz**	**360.525 MHz**

Hence, when this Cell Extender system would process an Intersite call on Donor System Traffic Channel 120, the Cell Traffic Channel Tx would be transmitting on 350.525 MHz (Channel 121), whilst its companion Cell Extender Donor (RF link) radio would be receiving on 350.500 MHz (Channel 120), which is only 1 channel (25 kHz) spaced away. Such situations should of course be avoided wherever possible: the larger the (worst case) frequency spacing, the less critical the antenna system design will be.

Design Rule # 1

Always select the Cell Channels as far away as possible from any of the Donor channels.

3. Cell Extender Radio Frequency Agility - Impact on Antenna Combiner Design

Basically, the Cell (System Output) channels always operate on the same, fixed set of frequencies. Hence, normal common Antenna Combiner practice (application of cavity based multi couplers) applies equally to Cell Site radio combining equipment.

However, the Donor (RF link) radios are "frequency agile": they can be tuned to any Donor Site Traffic or Control channel. This does not matter much for the Donor receivers, as normal Rx splitter and/or amplifier techniques are readily used for Donor receivers as well.

Filter based Transmitter Combiners however can normally not be used for the Donor transmitters, as the switching bandwidth (typically 1.5 to 2.5 MHz) will generally be too wide for a standard filter based combiner.

Hence the Donor Transmit combiner is usually a passive, wide band "hybrid combiner". Hybrid combiners are simple, small and cost effective, but they are relatively lossy (typical insertion loss for a 3-port combiner for instance is 6.2 dB per path). This however is not a problem for Donor transmitters as their link path to the Donor site is point-to-point. (In fact, as we will conclude in Section 6 of this Document, this attenuation is often an advantage, as reduced Tx antenna input power reduces Site desense and interference effects).

Design Rule # 2

Use normal cavity based combiners for the Cell radio transmitters. Use (low cost) hybrid combiners for the Donor radio transmitters. Use standard Rx splitters for the systems receivers.

4. Calculation of Required Antenna Isolation

Two different effects govern the requirements on a Cell Extender antenna system design:

a) The radio's Receiver Selectivity which distinguishes into:

- The "Adjacent Channel" (= Close In) Selectivity

- The "Blocking Performance" (= Selectivity spaced further away)

b) The radio's Transmit Sideband Power, which also breaks down in its "Adjacent Channel sideband power", and its sideband power level further away from the carrier.

**For the purpose of this Document we will use the following typical figures.
These parameters will be generally similar or better for most types of radios.**

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4.1 Typical Radio Selectivity and Performance Figures

Frequency Spacing (kHz)	Rx Selectivity	Tx Sideband Power
Nil ("On Channel")	0 dB (reference)	0 dB (reference)
Adjacent Channel	75 dB	- 75 dB (* Modulated!)
At 2 channel spacings	85 dB	- 85 dB
At 1 MHz:	100 dB	- 100 dB

4.2 Isolation Calculations

Now let us assume the following typical Tx power levels and minimum Rx input levels:

Donor Tx Power (*):	+ 30 dBm (1 Watt)
Cell Tx:	+ 46 dBm (50 Watts less combiner losses)
Donor Rx Input Level (*):	- 100 dBm (typical figure)
Minimum Workable Cell Rx Input level:	- 115 dBm

(*) Note. Please refer to Section 6 for a further analysis of these parameters.

The total path loss figures are now *(Note *):*

Donor Tx to Cell Rx:	+ 30 dBm + 115 dBm = 145 dB
Cell Tx to Donor Rx:	+ 46 dBm + 100 dBm = 146 dB

**** Note. We are not addressing here the isolation required between Cell Tx and Cell Rx, or Donor Tx and Donor Rx, which are governed by common standard antenna system technologies (e.g. application of duplex filters or diplexers).***

So, broadly, we need a total isolation of 145 dB for both signal paths.

As the system's input and output frequencies are relatively close, we can not achieve much isolation by filtering. In addition, Donor radio frequencies are frequency agile, so filtering in this path is not possible at all. Furthermore, whilst there are of course differences between various makes and types of radios in terms of "close in" RF performance, most radios have the same, typical Rx selectivity and Tx out-of-band performance (to meet the various Regulatory requirements). Hence, the only tool available to work up a satisfactory overall RF system isolation is to use the antenna isolation between the systems Donor and Cell radio antennas.

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By deducting the radio's RF blocking and Tx sideband power figures from the above overall total path figures we can now obtain the "worst case" antenna isolation required for the System:

For 1 channel spacing:	**145 less**	**75 dB**	**=**	**70 dB**
At 2 channel spacings:	**145 less**	**85 dB**	**=**	**60 dB**
At 1 MHz spacing	**145 less**	**100 dB**	**=**	**45 dB**

Note!

We emphasise that these are broad, typical figures only, and these parameters may differ from case to case in actual practice. However, the numbers will give a good starting point for basic system design.

As a "rule of thumb" we can say that a typical isolation of 60 dB will provide adequate system performance. If a "worst case" spacing of 1 channel is absolutely inevitable, the isolation must be ideally be 70 dB or greater to ensure satisfactory system performance. This level of isolation can be achieved by adequate vertical antenna spacing of the Cell and Donor antennas.

Design Rule # 3

The antenna system must be designed to provide sufficient RF isolation between Donor and Cell radio antennas. This is generally achieved by perfect vertical (exactly co-linear) spacing between these antennas.

The Table below gives typical Antenna Isolation figures as a function of Vertical Spacing Distance.

Isolation (dB)	**Required Vertical Spacing**		
	160 MHz	**450 MHz**	**850 MHz**
50	**8 meters**	**4 meters**	**2.5 meters**
60	**11 meters**	**5.5 meters**	**3 meters**
70	**-**	**10 meters**	**6 meters**

Note 1.

The antennas must be EXACTLY co-linear, i.e. mounted precisely above one another!!

Note 2 (Source: Polar Industries, Melbourne, Australia, Email polar@polarelec.com.au

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These isolation figures are also applicable to High Gain antennas, provided:

a) The spacing is measured between the physical center of the antennas

b) The antennas are mounted directly above one another, *with no horizontal offset, that is, exactly co-lineair)*

c) The spacing is at least one half of the signal's wave length (this should always be the case for the spacings in the above Table).

It should be noted that the obtainable isolation figures in actual practice will also depend on tower construction, proximity of other structures, etc.

4.3 Using Duplexers to combine Tx and Rx antenna paths

It is not uncommon for Cell Extender antenna systems to use a total of three, or even four antennas.

A typical 3-antenna system design for instance uses 2 transmit antennas, 1 for the Cell radio transmitters, 1 for the Donor radio transmitters, and the third antenna is the receive antenna used by both Cell and Donor receivers (using a suitable splitter/amplifier system). A typical 4-antenna system design uses separate antennas for Donor and Cell receivers rather than a splitter system.

If there is plenty of "tower real estate" available on the antenna mast, a multiple antenna system may well be the most economical option. However, in most applications the available tower space is limited and/or restricted by other factors (like the proximity of other antennas).

For that reason we generally recommend the use of (standard) duplexers, to combine the transmit and receiver paths for both Donor and Cell radios into common antenna paths. This will result in a better, more consistent and predictable definition of the antenna system performance in general, and also, will allow a much increased worst case vertical spacing between Cell and Donor antennas (as there are 2 only to take into account as against 3 or 4 in the alternate case).

The Cell radio duplexer would generally be a high performance, high power band pass type of duplexer, but the Donor radio duplexer function can often be provided by a simple, low cost "mobile"(notch) type of duplexer, since the Donor radio RF transmit power is very limited and also, increased losses, if within reason of course, do not really matter much (may in fact help, see Section 6 below). Furthermore, the bandwidth of a simple notch type duplexer is often still wide enough to cover the frequency spread of the Donor channels (especially at UHF frequencies).

Design Rule # 4

We recommend the use of duplexers to combine Tx and Rx paths, especially where tower real estate is limited.

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4.4 Use of High Gain antennas for Donor radios

It is obviously advantageous to use high gain antennas for the Donor signal path:

a) The received Signal strength from the Donor site will be much higher than would be the case otherwise. This in turn means that the Cell Tx to Donor Rx interference path is significantly less critical, essentially reducing the required isolation figure by the same amount as the antenna gain used.

b) The actually radiated Donor Tx power can be reduced by the same amount as the gain of the antenna (for the same quality signal at the distant Donor Site). As in case a) above, this means an equivalent reduction in the required antenna isolation.

Design Rule # 5

Always use High Gain (Yagi) antennas for the Donor radio path. This reduces the required System isolation figures by the same amount as the antenna gain figure.

5. Donor Radio Signal Path Losses

The radio link(s) to the Donor site are point-to-point paths which in most cases, will be "Line of sight", or close to it. Hence, we can in the first instance apply Free Space attenuation figures for this path.

Typical Free Space Attenuation as a Function of Horizontal Spacing (Path Distance)

Distance (KM)	VHF (160 MHz)	UHF (470 MHz)
25	100 dB	109 dB
40	104 dB	113 dB
80	114 dB	123 dB

A successful Cell Extender Antenna System design will capitalise on the advantage of the point-to-point path between Cell site and Donor site, resulting in the relatively low path losses. Generally, there is no advantage in being "better than best". That is, there is no point transmitting back to a Donor site at a level of tens of Watts if a few hundred mWatts (or less) is sufficient. The advantage of not transmitting at excess power levels is an equally diminished Site Interference potential (and where applicable, reduced Site DC power consumption as well).

The same applies to the reverse path - we know that the Donor Site normally transmits at a full 50 Watt (or more) power level, and our System design can safely take that into account when calculating the minimum received signal strength from the Donor site.

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Example

Assume an actual path loss of 120 dB (say, a distance of 40 KM at VHF, allowing for some extra losses as well). We further assume Unity Gain antennas at the Donor Site and 10dB Yagis at the Cell site. Hence, we can add a gain of 10 dB to this path loss, i.e. the actual overall path attenuation is 120 less 10 = 110 dB.

For the Donor site to Cell site path we now get a Received Signal Strength of +47dBm less 110 dB = - 73 dBm. A signal strength of (say) - 90 to -100 dBm is more than adequate for most applications. So the excess margin of some 20 to 30 dB in the actually received signal strength will give a further substantial margin against any possible Cell Tx to Donor Rx interference effects.

The reverse path: the case of Donor (RF link) radio key ups possibly affecting the received Cell radio receiver signals is generally more critical. We want the Cell Receiver to still operate OK, without any serious desense effects, at levels as low as (say) - 120dBm, to achieve the best possible System coverage (sensitivity).

The desense effect by Donor transmitter key ups on Cell radio receivers is directly dependent on the actually radiated Donor Transmit power level. So, the lower the Donor radio transmit power level, the better the desense performance.

To find the actually required minimum RF power level, we would conservatively design for a receive level at the Donor site of (say) - 90dBm. Working again with a typical path loss of 120 dB less 10 dB (for the antenna gain) = 100 dB between Cell and Donor sites, the Donor Transmit level at the Cell site should be -90dBm + 110 dB = + 20 dBm, or 100 mWatts!

Most commonly used Donor radios can be adjusted to Tx output level as low as a few Watts. With the attenuation of the Hybrid combiners in the Donor Tx path, the actual radiated power level is therefore commonly around the 1 Watt level.

This may still be well in excess of what is actually required. Especially when RF interference and/or desense effects are experienced in the Cell to Donor traffic direction we recommend the use of a fixed attenuators in the Donor Tx antenna line. Since the power at this point is limited to a few Watts only, a power rating of 5 Watts, or even less, is generally more than adequate. Such attenuators are of low cost and readily available from any common RF component supplier.

Design Rule # 6

To minimise Cell receiver desense effects caused by Donor radio key ups, never operate Donor Transmitters at power levels beyond what is needed for an (adequate) minimum. This means that in actual practice the actually radiated Donor radio transmitter power level will rarely be in excess of a few hundred mWatts. Use external attenuators to reduce actual EIRP levels if this can not be achieved by the radios Tx power adjustment facility.

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6. On Site Antenna System Testing

The following tests may be carried out to measure and check the isolation of an actual antenna system. It assumes availability of a suitable signal generator and receiver device (e.g. an IFR Test Set or similar). Other methods can be used as well (e.g. a Spectrum Analyser to measure output levels and attenuation figures).

- Set the Test Receiver Mute to a typical threshold level (e.g. 15 dB Sinad). The RF level of the Signal Generator is noted (A dBm).

- Now connect the RF signal generator to the Cell Tx Antenna input. Connect at the input of the Tx multicoupler.

- Connect the Test Receiver to the Donor Rx antenna. Connect at the output of the Rx multicoupler.

- Slowly increase the RF level from the signal generator until the Test receivers Mute breaks again. Note the new level (B dBm).

The antenna isolation between Cell Trasnmitter and Donor Receiver is now (B-A) dB.

- Repeat the above procedure for the opposite path (i.e. Donor Tx to Cell Rx).

The isolation measured should be in the order of 60 dB or greater. Experiment with the set up if/when necessary to further improve the antenna isolation.

7. Summary of Cell Extender Antenna System Design Rules

Design Rule # 1:

Always select the Cell Channels as far away as possible from any of the Donor channels. Where possible, give the Cell Control channel the "advantage".

Design Rule # 2

Use normal cavity based combiners for the Cell radio transmitters. Use (low cost) hybrid combiners for the Donor radio transmitters. Use standard Rx splitters for the systems receivers.

Design Rule # 3:

The antenna system must be designed to provide sufficient RF isolation between Donor and Cell radio antennas. This is generally achieved by perfect vertical (exactly co-linear) spacing between these antennas.

Design Rule # 4:

We recommend the use of duplexers to combine Tx and Rx paths, especially where tower real estate is limited.

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Design Rule # 5:

Always use High Gain (Yagi) antennas for the Cell site to Donor site path. This reduces the required System isolation figures by about the same amount as the antenna gain.

Design Rule # 6:

To minimise Cell receiver desense effects caused by Donor radio key ups, never operate Donor Transmitters at power levels beyond what is needed for an (adequate) minimum. This means that in actual practice the actually radiated Donor radio transmitter power level will rarely be in excess of a few hundred mWatts. Use external attenuators to reduce actual EIRP levels if this can not be achieved by the radios Tx power adjust