

TRANSMITTER INTERFERENCE REJECTION

FIELD OF THE INVENTION

The present invention relates generally to the use of antenna array systems used in e.g., mobile radio systems, and more particularly to the techniques for reducing interference between such arrays.

RELATED ART

The demand for capacity in base station sites used in mobile radio communications systems is increasing rapidly. A consequence of this is an increase in the demands on the antenna systems used in such radio systems. An arrangement of typical components in the transmitter path for a mobile radio system is shown in Figures 1 and 2. Shown are a splitter 50, amplifier 40, isolator 30, filter 20 and antenna element 10.

The most common method of implementing antenna systems is to use one amplifier which is not placed up in the antenna column. Another method is to use one amplifier placed in the transmitting tower. An example of this is shown in Figure 1. Illustrated here are three columns 1-3 of transmitters as might typically be found on a transmitting tower at a base station in a mobile radio communications system. Associated with several antenna elements, 10a-10d, will be one splitter 50, one amplifier 40, one isolator 30, and one filter 20. The signal to be transmitted is sent to the amplifier 40 from the base station, not shown here, before being sent to the one splitter 50, which will divide the radio signal to be transmitted to a number of antenna elements 10a-10d.

Another method being used in some systems is to provide a separate amplifier placed up in the transmitting tower for each antenna element. A system such as this is shown in Figure 2, with three columns 1-3 of transmitters as might typically be found on a transmitting tower at a base station in a mobile radio communications system. It can be seen that the signal is first sent to a single splitter 50 from a base station, not shown here, where the signal is split before being sent to the respective antenna elements 10a-10d to be broadcast. Each antenna element 10a-10d will then have its own amplifier, 40a-40d respectively, isolator, 30a-30d respectively, and filter, 20a-20d respectively.

The antenna columns containing elements 10a-10d shown in Figures 1 and 2 are usually mounted in arrays on transmitting towers. They can be mounted in linear or circular arrays. An example of a common circular array on a tower is shown in the top view of Figure 3a. Shown here are four columns 1-4 spaced every 90 degrees around a transmission tower 5. Each column contains an array of antenna elements 10a-10d as illustrated in Figure 1. Only the top antenna element 10a, corresponding to the top antenna element 10a in Figures 1 and 2, is shown. It can be appreciated that the number and spacing shown here are for illustration only. A typical system will probably have 8 or 16 antenna elements for each column.

Shown in Figure 3b is a corresponding front view of the same tower as in Figure 3a. A front column 4 and two side columns 1,3; each having four antenna elements 10a-10d are shown. The back column 2 is not visible behind the transmission tower 5. This arrangement of antenna elements is sometimes used for Space (or "Spatially") Divided Multiple Access("SDMA"), a method

of combining transmitters geometrically in space to provide efficient access to the radio transmitters and receivers.

Due to problems with space limitations, especially in urban environments, the antenna elements 10a-10d are arranged quite close together. They are also arranged quite close to each of their amplifiers, e.g. 40 Figure 1, isolators, e.g. 30 Figure 1, and filters, e.g. 20 Figure 1. This tight arrangement in arrays greatly increases the risk of interference. It also increases the equipment requirements on the filter and isolator due to other carrier interference risk from adjacent antenna columns.

In those antenna systems having a separate amplifier for each antenna element, see Figure 2, the amplifiers 40a-40d are usually operated in a non-linear mode, although they may be operated in linear mode. It is well known in the art that a non-linear amplifier receiving signals of two different frequencies will provide outputs at each of those two frequencies as well as intermodulation ("IM") product outputs at the sum and difference frequencies of those two signals. In these tight arrangements of antenna arrays, a given antenna element 10a-10d will receive quite strong interference signals from adjacent arrays.

This interference signal will be forced back through the filter 20a-20d and isolator 30a-30d to the power amplifier 40a-40d where it will mix with the desired signal to form the IM products. These IM products often interfere with the desired frequencies. This problem of reducing the risks of intermodulation interference has been faced using several different methods in the past.

One method has been to operate the amplifiers in a linear mode so that IM products are not generated, or are at least held to a minimum. This is a poor solution, however, because linear

amplifiers have a low DC-to-RF efficiency which will significantly hinder the operation of the array.

Another approach is shown in US 4,498,083 which involved cancelling multiple sources of interference in an antenna array.

5 It provided a technique of checking the phase angle of an incoming interference signal and then using phase shifters to vary the received signal in relation to the interfering signal. Each interfering signal required a doubling of elements need to deal with the signal; for example 4 interfering signals would
10 require 16 elements in a linear array.

Although the basic problem dealt with in US 4,498,083 was similar, the specific problem was different. It dealt more specifically with independently tracking and varying the phase of a multiple of interfering signals. The problem and solution
15 were different than that in the present application.

Another example of a prior approach is in US 4,500,883. Again, here the problem was that of independently tracking and cancelling interfering signals from multiple sources. The basic idea was to provide a means so that the interfering signal
20 arriving at any pair of antenna elements would arrive 180 degrees out of phase. A servo motor was provided to adjust the position of the antenna elements in response to measured levels of interference. This technique is also quite different from that of the present invention.

25 Yet another example of prior approaches is found in US 4,314,250 which was more specifically focused on the intermodulation products that result from active type of antennae where each antenna element is provided with its own amplifier, as in the present invention. The invention in this patent adjusted the
30 phase tilt of the carriers across the array of antenna elements.

Although the technique of US 4,314,250 does decrease the intermodulation products in active type antennae, it does so by changing the phase tilt of the carrier frequencies.

SUMMARY OF THE INVENTION

5 As has been seen, to achieve high power output in many modern mobile radio stations, each antenna column uses one amplifier placed up in the transmitting tower per antenna element. Each component will have its own isolator and filter also, resulting in a large number of components. One factor affecting the size
10 and cost of these components are intermodulation ("IM") products. Any technique which can increase the IM product rejection will result in decreased requirements on these other components.

Accordingly, it is an object of the present invention to reduce
15 interference between antenna arrays in a mobile radio station, each array including a number of antenna elements, creating certain and different transmission lengths for each antenna element so that the sum of IM products will not appear coherent from the antenna column. This can be accomplished by dividing
20 the transmission length from the power output of the amplifiers to the antenna elements into N phases, where N is the number of antenna elements on the antenna column. The amplifiers may be single carrier or multicarrier amplifiers.

This object creates an incoherent sum of IM products from the
25 antenna column. However, by itself, it creates an incoherent sum from the desired transmitted signals also. Accordingly, it is another object of the present invention to compensate the length in the transmission length from the amplifiers to the antenna elements with a corresponding offset in transmission length at
30 the input transmission line of each power amplifier.

Briefly described, the present invention accomplishes the above and other objectives in the following manner. An antenna column is used, with N antenna elements, each with its own power amplifier, isolator and filter. The first element $N=1$ is at the top of the column. Each succeeding element is directly below the previous element, so that $N=2$ is directly below $N=1$, and so on until we reach the bottom element $N=N$.

A length dL is calculated based on the electronic wavelength L . The transmission length between the first amplifier and the first antenna element is L . The transmission length between the second amplifier and the second antenna element is $L+dL$. Each succeeding transmission length is increased by a length dL , so that the third transmission length is $L+2dL$, the fourth is $L+3dL$, and so on. The transmission length between the N th amplifier and the N th antenna element will then be $L+(N-1)dL$.

This will result in a "steering" of the column of IM products, effectively creating an IM beam that is tilted downwards or upwards. The result is that the IM products will not appear coherent to other adjacent antenna columns at the base station. However, the desired signals to be transmitted will also be "steered" unless some means is provided to prevent this. This can be done by first noticing that the total transmission length for the desired signal can be divided into two parts, from the splitter to the power amplifier, then from the power amplifier to the antenna element.

In the present invention the transmission length from the power amplifier to the antenna element increases by an amount dL as we proceed from the first amplifier-element pair through the last. In order to keep the total transmission length constant as we proceed from first amplifier-element pair through the last, we then need to subtract this length dL from the transmission

length between the splitter and the power amplifier. Accordingly, the transmission length between the splitter and the power amplifier for the first amplifier will be L .

The transmission length between the splitter and the amplifier for the second amplifier will be $L-dL$. This will continue in a manner such that the transmission length between the splitter and the amplifier will decrease by an amount dL for each successive amplifier. The length between the splitter and the amplifier for the N th amplifier will then be $L-(N-1)dL$. The result of this is that the total transmission length for the desired radio signal remains a constant $2L$ for each splitter-amplifier-antenna element path. The path for the IM products is shifted as described above so that it is not coherent in relation to the desired signal or in relation to adjacent antenna columns.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described in more detail with reference to preferred embodiments of the present invention, given only by way of example, and illustrated in the accompanying drawings, in which:

FIG. 1 is a diagram of three antenna columns with four antenna elements each, wherein only one amplifier and filter and isolator are provided for all the antenna elements.

FIG. 2 is a diagram of three antenna columns with four antenna elements each, wherein each antenna element is provided with its own amplifier and filter and isolator.

FIG. 3a is a top view of a radio transmission tower having four columns of antenna elements in a circular array.

symbolised by block 100a, the signal travels to the first amplifier 10a is equal to L , which is also equal to the distance of a second part of the signal path, symbolised by block 110a, the signal must subsequently travel from the first amplifier 40a to the first antenna element 10a. It is seen that the total distance travelled for the signal from the splitter 50 to the first antenna element 10a is $2L$.

This contrasts with the distances for antenna element number two 10b. Here the signal first travels a first part of the signal path corresponding to a distance 100b, equal to $L-dL$, to the second amplifier 40b before travelling a second part of the signal path corresponding to a distance 110b, equal to $L+dL$, between the second amplifier 40b and the second antenna element 10c. Here the signal travels again a total distance of $2L$ from the splitter 50 to the second antenna element 10b.

For each subsequent antenna element 10a-10h the first parts of the signal paths corresponding to the distances 100a-100h between the signal splitter 50 and amplifier 40a-40h are decreased, while the corresponding second parts of the signal paths corresponding to the distances 110a-110h between the amplifiers 40a-40h and antenna elements 10a-10h are increased. For any given amplifier 10a-10h numbered N , $N=1-8$, the distance travelled by the signal from splitter 50 to amplifier 40a-40h is $L-(N-1)dL$. Therefore, for example, the distance travelled by the signal from the splitter 50 to the seventh amplifier 40g ($N=7$), is $L-6dL$.

For any given amplifier 40a-40h numbered N , $N=1-8$, the distance 110a-110h then travelled by the signal from the amplifier 40a-40h to its corresponding antenna element 10a-10h is equal to $L+(N-1)dL$. So, for example, the distance 110h travelled by the signal from the eighth amplifier 40h ($N=8$) to the eighth antenna

FIG. 3b is a front view of the radio transmission tower in Figure 3a having four columns of antenna elements in a circular array.

FIG. 4 illustrates cutaway view of the preferred embodiment of the present invention wherein the transmission lengths are varied to provide equal distant phase generation for the IM products.

FIG. 5 illustrates a cutaway view of an alternative embodiment of the present invention wherein the transmission lengths are varied to provide opposite phase generation for the IM products.

FIG. 6 shows the phase vector diagrams for both the preferred embodiment and the alternative embodiment.

DETAILED DESCRIPTION

In Figure 4 is seen the preferred embodiment of the present invention, an equal distant phase intermodulation ("IM") product generation for the case of an 8 dipole antenna column. It can be appreciated that an 8 dipole column is chosen here for ease of explanation, and the present invention will work for any number of antenna elements in a column. The radio signal begins at a source 60 located in the base station, not shown here. The signal is split in a splitter, 50 Figures 1, 2, and then sent to the various antenna elements 10a-10h along a variety of paths 70a-70h. Each antenna element 10a-10h has its own amplifier 40a-40h and filter-isolator 25a-25h (shown located together for illustration purposes).

The distance L is the electrical wavelength. A distance dL is then calculated from $dL=(L/2)/N$, where N is the number of antenna elements 10a-10h in the column. In Figure 4 $N=8$, so $dL=(L/2)/8$. The distance of a first part of the signal path,

element 10h is equal to $L+7dL$. However, it will quickly be seen that the total distance travelled by the signal in every case from the splitter 50 to antenna element 10a-10h is $2L$. Therefore the distance travelled by the desired signal remains in phase in every case.

The situation is far different, however, when we consider the IM products. Interfering signals are received from nearby antenna columns at the various antenna elements 10a-10h along a given column. These interfering signals are then forced backwards from the antenna element, e.g. 10a, through the filter and isolator, 25a respectively, to the amplifier, 40a respectively. They then combine with the desired signals to create IM products which are transmitted back from the amplifier 40a through the filter and isolator 25a to the antenna element 10a, where they are transmitted to the air interface.

In a normal situation the IM products created by a given interfering signal would be reflected back along a plane parallel to the antenna column. This is due to the fact that the interfering signals we are primarily concerned with here are those from adjacent antenna columns. They will arrive to adjacent columns on the tower in phase and then be transmitted back in phase.

In the embodiment of the present invention shown in Figure 4, however, the interfering signal, and therefore the corresponding IM products, will be forced to travel a longer distance for each subsequent antenna element. For example, the distance the IM products must travel is L for the first antenna element 10a, while it is $L+7dL$ for the eighth antenna element 10h. It can be seen that the distance travelled for the IM products increases as we proceed from the first antenna element 10a to the eighth

10h. This produces a greater delay as we move from the first element 10a to the eighth 10h.

This delay causes a tilt in the wavefront of the IM products wave produced from a given interfering signal. However, as we saw above, the desired signal arrives at each antenna element 10a-10h simultaneously, so there is no tilt in the wavefront for the desired signal. This shift in the relation of the phase of the desired signal in relation to the IM products results in redirected interference from the IM products.

Another embodiment of the present invention is shown in Figure 5. Similar to Figure 4, an opposite phase intermodulation ("IM") product generation for the case of an 8 dipole antenna column is shown. Here again an 8 dipole column is chosen here for ease of explanation, and the present invention will work for any number of antenna elements in a column. The radio signal begins at a source 60 located in a base station, not shown here. The signal is split in a splitter, 50 Figures 1, 2, and then sent to the various antenna elements 10a-10h along a variety of paths 70a-70h. Each antenna element 10a-10h has its own amplifier 40a-40h, respectively, and filter-isolator 25a-25h, respectively, (shown located together for illustration purposes).

The distance L is here again the electrical wavelength. A distance dL is then calculated from $dL = (L/2)/N$, where N is the number of antenna elements in the column. In Figure 5 $N=8$, so $dL = (L/2)/8$. The distance of the first part of the signal path, symbolised by block 100a, the signal travels to the first amplifier 40a is equal to L , which is also equal to the distance of the second part of the signal path, symbolised by block 110a, the signal must subsequently travel to the first antenna element 10a. It is seen that the total distance travelled for the signal from the splitter 50 to the first antenna element 10a is $2L$.

This contrasts with the distances for antenna element number two 10b. Here the signal first travels a first part of the signal path corresponding to a distance 100b equal to $L-dL$ to the second amplifier 40b before travelling a second part of the
5 signal path corresponding to a distance 110b equal to $L+dL$ between the second amplifier 40b and the second antenna element 10b. Here the signal travels again a total distance of $2L$ between the splitter 50 and the second antenna element 10b.

For each subsequent antenna element 10a-10h the first part of
10 the signal paths corresponding to the distances 100a-100h between the splitter 50 and amplifiers 40a-40h are alternated between L and $L-dL$, while the corresponding second parts of the signal paths corresponding to the distances 110a-110h between the amplifiers 40a-40h and antenna elements 10a-10h are
15 alternated between L and $L+dL$. For any given amplifier 40a-40h numbered N , N an odd number, the distance travelled by the signal from the splitter 50 to amplifier 40a-40h is L . For any given amplifier 40a-40h numbered N , N an even number, the
20 distance travelled by the signal from the splitter 50 to amplifier 40a-40h is equal to $L-dL$.

For any given amplifier 40a-40h numbered N , N an odd number, the distance then travelled by the signal from the amplifier 40a-40h to its corresponding antenna element 10a-10h is equal to L . For any given amplifier 40a-40h numbered N , N an even number, the
25 distance then travelled by the signal from the amplifier 40a-40h to its corresponding antenna element 10a-10h is equal to $L+dL$. So, for example, the distance travelled by the signal from the eighth amplifier ($N=8$) to the eighth antenna element is $L+dL$. However, it will quickly be seen that the total distance
30 travelled by the signal in every case from the splitter 50 to

antenna element 10a-10h is equal to $2L$. Therefore the distance travelled by the signal remains in phase in every case.

It can be appreciated by the symmetry of the situation shown in Figure 5 that the situation can be easily reversed between the
5 odd-numbered paths and the even-numbered paths. It is also possible to design the system so that the first four lengths from the splitter 50 to the first four amplifiers 40a-40d will all be equal to L . The lengths between the first four amplifiers 40a-40d and their respective antenna elements 10a-10d will also
10 be equal to L .

In turn, the lengths of the second four lengths from the splitter 50 to the second four amplifiers 40e-40h will all be $L+dL$. The lengths between the second four amplifiers 40e-40h and their respective antenna elements 10e-10h will all be $L+dL$. As
15 above, the symmetry here means that the lengths from the splitter 50 to the first four amplifiers 40a-40d can all be $L-dL$ while they would then be equal to L from the splitter 50 to the second four amplifiers 40e-40h. The lengths from the first four amplifiers 40a-40d to their respective antenna elements 10a-10d
20 will also be equal to $L+dL$ while from the second four amplifiers 40e-40h to their respective antenna elements 10e-10h will be equal to L .

The situation is again far different in this embodiment, however, when we consider the IM products. Interfering signals
25 are received from nearby antenna columns at the various antenna elements. These interfering signals then are forced backwards from the antenna element, e.g. 10a, through the filter and isolator, 25a respectively, to the amplifier, 40a respectively. They then combine with the desired signals to create IM products
30 which are transmitted back from the amplifier 40a through the

filter and isolator 25a to the antenna element 10a, where they are transmitted to the air interface.

In a normal situation the IM products created by a given interfering signal would be reflected back along a plane parallel to the antenna column. This is due to the fact that the interfering signals we are primarily concerned with here are those from adjacent antenna columns which reach an adjacent column in phase. In the embodiment of the present invention shown in Figure 5, however, the interfering signal, and therefore the corresponding IM products, will be forced to travel a different distance for each pair of antenna elements 10a-10h. For example, the distance the IM products must travel is L for the first antenna element 10a, while it is $L+dL$ for the second antenna element 10b. It is then L again for the third antenna element 10c and again $L+dL$ for the fourth antenna element 10d.

It can be seen that the distance travelled for the IM products alternates between L and $L+dL$ as we proceed from the first antenna element 10a to the eighth antenna element 10d. The wavefront for the IM products from the even numbered antenna elements, here 10b, 10d, 10f, and 10h, will be shifted in relation to the wavefront for the IM products from the odd numbered antenna elements, here 10a, 10c, 10e, and 10g. This will result in less coherence among the IM products.

However, as we saw above, the desired signal arrives at each antenna element 10a-10h simultaneously, so there is no tilt in the wavefront for the desired signal. This shift in the relation of the phase of the desired signal in relation to the IM products results in decreased interference from the IM products.

In Figure 6 is shown two phase vector diagrams for the embodiments shown in Figures 4 and 5. In the first diagram A it can be seen that the phase is divided into eight, corresponding to the eight different antenna elements of Figure 4. This illustrates that the phase of the IM products from each subsequent antenna element will be shifted further by one-eighth in relation to the carrier signal. It can be appreciated that a system with N antenna elements will divide the first diagram A into N. Compared with this is the second diagram B which corresponds to the embodiment shown in Figure 5. Here the IM products alternate between being in phase with the carrier to being 180 degrees out of phase.

The result of the present invention is a reduction in the IM products generated by the power amplifiers in antenna columns. Typical levels of IM products are about 80dBm. This can be calculated as:

$$IM_{30} = P_0 - IT_{Tx} - II - IM_3 - IL - IF$$

IM_{30} = IM3 output level

IT_{Rx} = Isolation between Rx and Tx antennas

20 IT_{Tx} = Isolation between Tx antennas

IL = Insertion loss Tx path

IM_3 = IM generated by Power amplifier

P_0 = Transmitter power output

IF = Isolation filter

25 IL = Isolation isolator.

Typical values might be: $IM_{30} = +33dBm - 30dB - 45dB - 15dB - 3dB - 20dB = -80dBm$. As the present invention lowers the IM products generated by the power amplifier the result is a lower output level of IM products. Expected improvements might be in the range of 10-

20dB, depending on the particular system implementations. The resulting improvements in IM output products can also allow lower standards required for the amplifiers, filters and isolators which can greatly save in costs.

- 5 The embodiments described above serve merely as illustration and not as limitation. It will be apparent to one of ordinary skill in the art that departures may be made from the embodiments described above without departing from the spirit and scope of the invention. Therefore, the invention should not be regarded
- 10 as being limited to the examples described, but should be regarded instead as being equal in scope to the following claims.

WHAT IS CLAIMED IS:

1. An antenna column, said antenna column having N antenna elements, N an integer greater than 1, each of said antenna elements having its own corresponding amplifier, filter-isolator, and a common radio source for transmitting radio signals of wavelength L to each of said N antenna elements by N fixed and different paths, characterised in that

each of said N fixed and different paths has a first part and a second part, said first part being the part of said path between a splitter shared by all N fixed and different paths and each said amplifier, and said second part being the part of said path between each said amplifier and its said corresponding antenna element, wherein the sum of the lengths of said first part and said second part of each path is equal to $2L$, and where the lengths of the different parts of the paths are chosen in a way so that the sum of the phase vectors of the intermodulation products is substantially zero.

2. The antenna column of Claim 1, characterised in that

the length of said first part of each of said N paths is equal

to $L - (n-1)\left(\frac{L}{2N}\right)$ and the length of said second part of said paths

is equal to $L + (n-1)\left(\frac{L}{2N}\right)$, n an integer varying between 1 and N .

3. The antenna column of Claim 1, characterised in that

the length of said first part of the odd numbered paths of said N paths is equal to L and the length of said second part of the odd numbered paths of said N paths is equal to L , and the length of said first part of the even numbered paths of said N



paths $L - \left(\frac{L}{2N}\right)$ while the length of said second part of the even numbered paths of said N paths is $L + \left(\frac{L}{2N}\right)$.

4. The antenna column of Claim 1, characterised in that

the length of said first part of the even numbered paths of said N paths is equal to L and the length of said second part of the even numbered paths of said N paths is equal to L , and the length of said first part of the odd numbered paths of said N paths $L - \left(\frac{L}{2N}\right)$ while the length of said second part of the odd numbered paths of said N paths is $L + \left(\frac{L}{2N}\right)$.

5. The antenna column of Claim 1, characterised in that

the length of said first part of the first $N=1$ to $N=N/2$ paths of said N paths is equal to L and the length of said second part of the first $N=1$ to $N=N/2$ paths of said N paths is equal to L , and the length of said first part of the $N=N/2$ to $N=N$ paths of said N paths equals $L - \left(\frac{L}{2N}\right)$ while the length of said second part of the $N=N/2$ to $N=N$ paths of said N paths is $L + \left(\frac{L}{2N}\right)$.

6. The antenna column of Claim 1, characterised in that

the length of said first part of the $N=N/2$ to $N=N$ paths of said N paths is equal to L and the length of said second part of the $N=N/2$ to $N=N$ paths of said N paths is equal to L , and the length of said first part of the first $N=1$ to $N=N/2$ paths of said N paths equals $L - \left(\frac{L}{2N}\right)$ while the length of said second



part of the first $N=1$ to $N=N/2$ paths of said N paths is

$$L + \left(\frac{L}{2N} \right).$$