Adaptive base-station antenna arrays

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Adaptive antenna systems represent an area in which considerable development efforts and field trials are being conducted to increase capacity in mobile communication networks. Ericsson has developed array antennas for use in the 900, 1800 and 1900 MHz frequency bands. Thanks to microstrip patch elements, Butler matrices, and several dual-polarized beams, these antennas yield high antenna gain and excellent spatial efficiency.

The authors describe adaptive antenna hardware and configurations as well as measured results from work on adaptive base-station antennas.

BOX A, ABBREVIATIONS

C/I	Carrier to interference ratio
ERP	Equivalent radiated power
GSM	Global system for mobile communication
RF	Radio frequency
TDMA	Time-division multiple access

Introduction

The rapid growth in the number of users of mobile communications means that many operators must find new ways of increasing the capacity of their networks. Their options include allocating more frequency, introducing frequency-hopping techniques, and adding microcells and adaptive antenna systems.

The introduction of new frequency bands at 1800 and 1900 MHz is an example of allocating frequency to increase capacity. However, compared to 800 and 900 MHz systems, mobile communication at 1800 and 1900 MHz requires more base stations or greater levels of radiated power.

Within the available frequency spectrum, capacity can be increased through the introduction of smaller cells, such as microcells, to create a dense network of base stations. Nonetheless, networks of this kind are often perceived as an aesthetic eyesore, due to the large quantities of associated antenna installations. Indeed, in many regions, the general public demand is for fewer antennas that are smaller in size and less conspicuous.

Another problem associated with adding numerous base stations is the cost involved in finding new locations for the antennas and base-station cabinets. Therefore, more and more operators are showing interest in adaptive antenna systems as a means of resolving their need for greater network capacity.

Ericsson has conducted extensive research and development of advanced base-station antennas for mobile communication. This work comprises both adaptive and active antenna systems. With the introduction of active antenna products, such as Ericsson's Maxite products, operators can now use small-sized base station units with high levels of equivalent radiated power (ERP) and low power consumption.

Ericsson has vast experience of array antenna products which, thanks to a superior design practice and the integration of antenna and electronic components, make attractive system solutions.[1-4] Product examples found in commercial and defense applications include

- Maxite active antennas (Figure 1);
- the MINI-LINK family (Figure 2;
- Erieye airborne early-warning radar (Figure 3); and
- Arthur artillery hunting radar (Figure 4).

Figure 1
Maxite active antenna and base station.

Figure 2
MINI-LINK with integral antenna.

Discrete base-station antennas

Traditional installations of mobile communication base-station antennas make use of space-diversity techniques, which require at least two antennas pointing in the same direction and separated from each other by a distance of 10 to 20 wavelengths.

An alternative to space diversity is polarization diversity, which also reduces antenna visibility.

Polarization diversity increases gain through the simultaneous reception of two orthogonal polarized signals from a single, dual-polarized antenna. In most instances, polarization diversity is just as efficient as space diversity. Thus, the introduction of polarization diversity means that the antenna installation may consist of a single antenna unit used for both transmission and reception. In addition to being more aesthetically pleasing, this solution is often easier and more cost-effective to install. Figure 5 shows an adaptive-antenna array installation at an existing site. In total, the site has nine sector antennas oriented in three different directions. In each direction, one transmission antenna and two receive antennas use space diversity. Each set of three antennas can be replaced with the much smaller installation of a single, adaptive-antenna array, which yields approximately the same antenna gain and coverage as the traditional arrangement.

Adaptive antenna configurations

Adaptive antenna systems offer a promising way of increasing network capacity. The antenna arrays in these systems have a horizontal extension that enables narrow antenna beams to be created in the azimuth plane. An antenna array also makes it possible to obtain angular resolution in the horizontal plane (azimuth angles) that can be accessed in order to identify the position of mobile terminals and to assess traffic distribution.

In principle, narrow beams directed toward a mobile terminal reduce interference levels in the network and thereby increase capacity. With the proper choice of receiver algorithms, it is possible to attain a good carrier-to-interference (C/I) ratio in signals received from a mobile terminal. Angular directions to mobile terminals and interferers may also be determined, which gives sufficient information for making an intelligent choice of transmit beam with

- high amplitude levels toward the target mobile terminal; and
- low interference levels in other directions.

Several methods can be used for directing radiated power from an array antenna into a narrow beam. The required phase front along the antenna elements that correspond to a scanned narrow beam can be generated either through digital beam forming in the transceivers or at radio frequency (RF), using passive networks or phase shifters.

Regardless of the method used, beam forming is required to ensure phase coherency all the way from the beam former to the antenna elements. When digital beam forming is performed in the transceivers at the base station cabinet, the feeder cables between the cabinet and the antenna must remain in phase for their entire lifetime.

One the other hand, a passive beam-forming network at the antenna does not require phase coherence between the radio transmitters and the beam former, which allows the feeder cables to have arbitrary phase. With RF beam forming in the antenna, phase coherence is easily achieved, since the phase requirements only involve transmission lines within the antenna unit

Figure 3
Erieye airborne early-warning radar.

TRADEMARKS

ERIEYE™, Maxite™ and MINI-LINK™ are trademarks owned by Telefonaktiebolaget LM Ericsson, Stockholm, Sweden.

Figure 4
Arthur artillery hunting radar.

Figure 5
A TDMA 1900 adaptive antenna installed at a traditional three-sector site together with space-diversity antennas.

itself, as part of the standard design of an antenna array. One example of a passive network is the Butler matrix, which generates a set of simultaneous orthogonal beams from a single array antenna and minimizes beamforming loss. A crossover gain drop between the orthogonal beams must be considered in the system design. Ideally, gain at the crossover point using a Butler matrix is 3.9 dB less than beam peak gain.

Antenna arrays

Ericsson has developed two-dimensional antenna arrays for adaptive base-station systems. These arrays, which are developed for

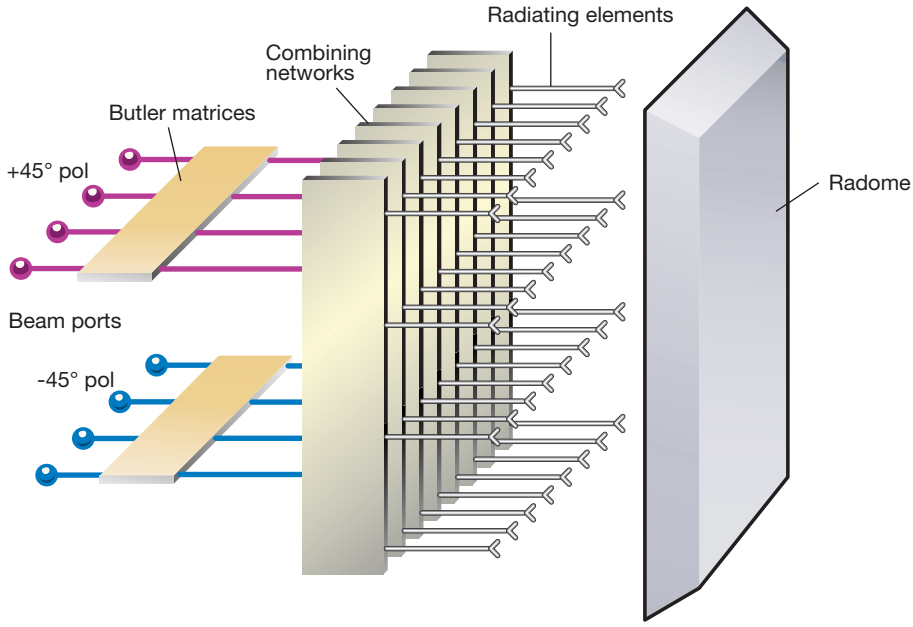

Figure 6
Principles of a multibeam array antenna.

systems based on GSM and TDMA (IS 136) standards, work in the 900, 1800 or 1900 MHz frequency bands. Together with Mannesmann Mobilfunk GmbH (GSM) and AT&T Wireless Services (TDMA), Ericsson has conducted field trials in live networks to evaluate the performance of the adaptive systems. The results show that adaptive antenna systems considerably increase capacity.

The adaptive array antenna transmits and receives radio-frequency signals in directed narrow beams. Figure 6 shows a principle view of a multibeam array composed of a dual-polarized multibeam antenna with four azimuth beams in each of two orthogonal polarizations. The orientation of the polarization is slant linear ±45°. The radiating elements are aperture-coupled microstrip patches, located in columns spaced half a wavelength apart. For each polarization, the radiating elements in each column are combined in a vertical network. One horizontal beam-forming network (that is, the Butler matrix of each polarization) combines the radiating element signals to beam ports: four beams with +45° polarization and four beams with -45° polarization. A radome is placed in front of the antenna to protect it from the environment. The same array antenna is used both to transmit and receive, and must work over the entire system frequency band. A broadband design of the aperture-coupled patches and feed networks makes this possible.

In GSM as well as TDMA, base stations must occasionally transmit a control channel simultaneously over the entire sector region. To satisfy this requirement, a separate sector antenna function has been introduced as part of the adaptive antenna system. An effective solution uses an additional column of radiating elements next to the array antenna columns. For best results, the deviation between the sector antenna radiation pattern and the array antenna multibeam pattern must be as small as possible.

Besides increased capacity, the increase in antenna gain may also be exploited to offer greater coverage. The gain of the GSM 900 array (Figure 7) is comparable to that of a

Figure 7
A GSM 900 multibeam array antenna.

REFERENCES

1 Dahlsjö, O., Ljungström, B. and Magnusson, H.: Fibre-Reinforced Plastic Composities in Sophisticated Antenna Designs, Ericsson Review 64 (1987):2, pp. 50-57.
2 Derneryd, A. and Wilhelmsson, H.: Dichroic Antenna Reflector for Space Applications, Ericsson Review 68 (1991):2, pp. 22-33.
3 Dahlsjö, O.: Antenna Research and Development at Ericsson, IEEE Antennas and Propagation Magazine 34, (April 1992): 2, pp. 7-17.
4 Ahlbom, S., Andersson, P. and Lagerlöf, R.: A Swedish Airborne Early Warning System Based on the Ericsson ERIEYE Radar, Ericsson Review 72 (1995):2, pp. 54-63.

BOX B, TERMS AND DEFINITIONS

C/I
The ratio between the received desired signal and interference signals, usually expressed in dB.

ERP
In a given direction, the relative gain of a transmitting antenna with respect to the maximum directivity of a half-wave dipole multiplied by the net power accepted by the antenna from the connected transmitter.

Grating lobe
A lobe, other than the main lobe, produced by an array antenna when the interelement spacing is sufficiently large to permit the in-phase addition of radiated fields in more than one direction.

Orthogonal polarization
In a common plane of polarization, the polarization for which the inner product of the corresponding polarization vector and that of the specified polarization is equal to zero.

Phase coherence
Each antenna element must be supplied with the correct phase of signal in order to preserve the overall desired beam shape. This means that phase matching must be exact from the point of beam forming to the individual radiating antenna elements.

Polarization diversity
Orthogonal polarization components are used to provide diversity reception. Two-branch diversity is provided with a single antenna unit with dual-polarized radiating elements.

Radome
A cover usually intended for protecting an antenna from the effects of its physical environment without degrading its electrical performance.

Space diversity
Multiple receiving antennas are used to provide diversity reception. Base-station antennas must be spaced far enough apart to achieve decorrelation.

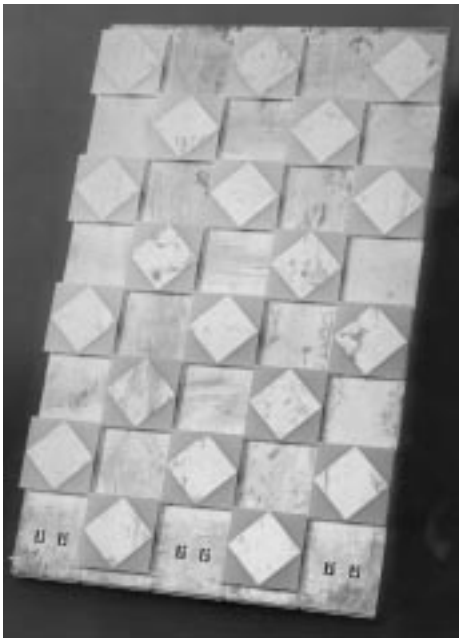

Figure 8
Radiating element layout of an array antenna with integrated sector antenna.

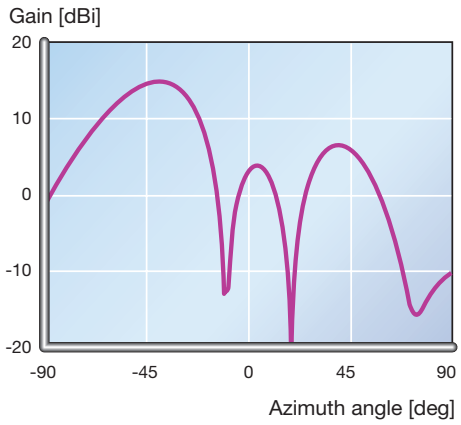

Figure 9
Beam radiation pattern: beam port no. 1.

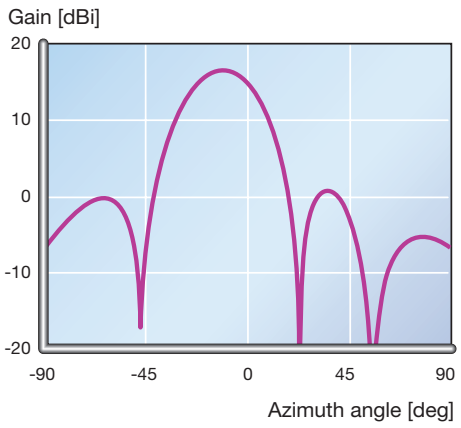

Figure 10
Beam radiation pattern: beam port no. 2.

traditional sector antenna more than twice as high.

A sparse grid of elements minimizes feed network losses and coupling effects between radiating elements. On the other hand, to maintain control over the beam pattern at all beam positions, grating lobes may not be generated. Figure 8 shows an effective element pattern layout in which the radiating element positions have been optimized to avoid grating lobes even at the outermost beams.

The antennas described in this article use Butler matrices to produce horizontal beamforming networks. A Butler matrix has an equal number of antenna ports and beam ports. For each polarization, a separate Butler matrix is connected to the columns of microstrip patches. By interleaving the beams of two polarizations, every other beam has the opposite polarization, which significantly reduces crossover depths between adjacent beams.

Figures 9-12 show the measured radiation patterns for the GSM 900 array. In particular, they show the four different beams of one polarization. Figure 13 shows each of the antenna's eight beams.

Improved power efficiency

Mobile communication base-station cabinets have traditionally been attached to pas-

sive antennas on a mast. To derive sufficient power radiation from these antennas, it has been necessary to use amplifiers with high output power and low-loss feeder cables.

Although high-power amplifiers are relatively efficient, the overall power efficiency of a traditional base station is low, since a lot of heat is generated at the base-station cabinets. Consequently, air conditioners must be installed, further reducing the total efficiency of the base station. Moreover, even when low-loss feeder cables are used, a considerable amount of power is lost in transit to the antenna as well as in the antenna power-combining/power-distribution network. A future introduction of adaptive antennas, which employ distributed power amplifiers along the antenna array close to the radiating elements, can greatly improve overall power efficiency.

Conclusion

Ericsson and cooperating operators have tested adaptive antenna systems in live GSM and TDMA networks, proving that these systems enable operators to increase the capacity of their mobile communication networks.

Moreover, the increase in gain derived from adaptive antenna systems enables operators to extend coverage from a compact antenna installation.

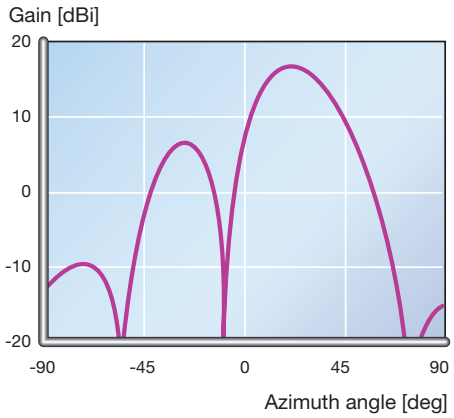

Figure 11
Beam radiation pattern: beam port no. 3.

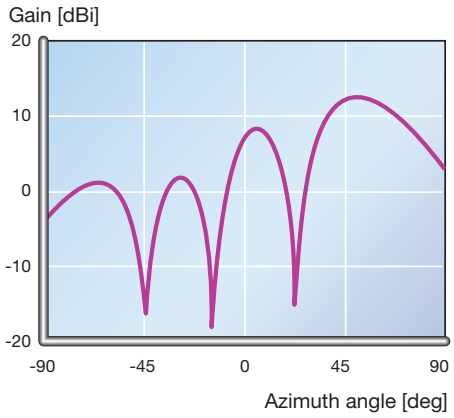

Figure 12
Beam radiation pattern: beam port no. 4.

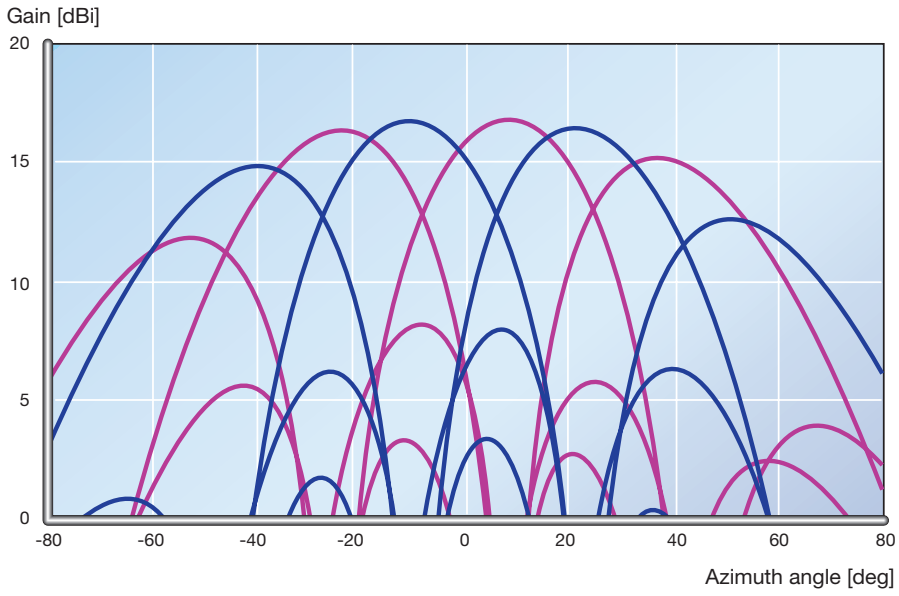

Figure 13
Measured radiation pattern of a GSM 900 array antenna showing all eight interleaved beams. The beams of one polarization are indicated by red lines; the beams of the other are indicated by blue lines.