

A New Generation of High-Power Cellular Repeaters

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ABSTRACT

This paper details the design concepts and applications of an EIA Type-IV Cellular Repeater being offered by The Antenna Specialists Company. This repeater is frequency-agile and translating, completely remote controlled and requires no system modifications, unlike earlier boosters that required donor-cell sectorization.

INTRODUCTION

Virtually every cellular telephone system has areas within its potential market territory where it would be profitable to enhance or supplement coverage if this could be done economically. These areas fall into three general categories:

- a) **Holes** - relatively small dead spots and zones of marginal operation within the system's existing service coverage.
- b) **Fringe areas** - areas at the edge of the existing coverage area where service would be desirable.
- c) **Corridors** - long, narrow zones of high traffic potential extending outward from the main service area or tying together two service areas. An obvious example is a busy interstate highway passing through regions of low population density.

All three types of system enhancement - hole filling, fringe expansion and corridor coverage - can be accomplished by adding or relocating cell sites, but the high cost of these solutions, versus the projected increases in revenues or improvement in system quality, usually makes these solutions difficult to justify. Recently, however, evolving technology has made it possible to improve existing system coverage much more economically with low-power, broadband cellular boosters and high-power, narrow-band cellular boosters (repeaters).

In general, a cellular booster or repeater is a dual-path RF amplifier system which picks up the

signals from an existing cell site (the donor cell) and amplifies them. Depending on the application being addressed, the booster then beams the amplified signals into a hole, outward into a fringe area, or down a corridor. Simultaneously, it picks up the signals from mobiles in the boosted coverage area, amplifies those signals, and beams them back to the donor cell.

This description of the basic operation is oversimplified, of course. It requires considerable design innovation and extensive experience in cellular systems to produce practical results in the field. Furthermore, a different type of cellular booster is usually required for each of the three general applications we've defined. This paper discusses a new type of high-power, frequency-translating cellular repeater designed to significantly extend the coverage range of a cell site (fringe expansion).

Low-power broadband cellular boosters such as the Antenna Specialists Co. Extend-A-Cell® II have gained wide acceptance by cellular operators who wish to fill small holes in their existing coverage areas or bring coverage into a building, tunnel, parking garage or other confined area. This type of device, under most conditions, only covers an area 1-2 miles from the booster site, and most often must use a high-gain directional coverage antenna. Isolation between coverage and donor (output vs input) antennas must be in the range of 85-95dB and effective radiated power is limited to approximately 3 watts per channel (with a 17dBd gain antenna and nominal feedline losses). For what they are intended, these low-power boosters perform very well.^[1]

As the large metropolitan systems mature, customers expect coverage further and further out into the suburbs. Rural systems under development, on the other hand, may project only enough subscribers to justify a single cell site. Both of these systems would benefit from a booster that would significantly extend coverage, but cost only a fraction of the amount of a conventional cell-site. The Extend-A-Cell® IV high-power repeater system has been designed with these applications in mind.

When determining whether an EAC-IV should be considered instead of a cell-site, one of the prime considerations is to determine what the real requirements are. A cell-site not only adds coverage, but also capacity. That is, it adds more channels to the system so that the system may accommodate additional users. The EAC-IV, on the other hand, only extends coverage. It borrows capacity from the "donor" cell site. Thus, a repeater may only be a temporary solution for 2 or 3 years until the system grows and additional capacity is needed. In low subscriber growth areas, however, the repeater may be a good solution for a much longer period of time.

A block diagram of the Extend-A-Cell IV repeater is shown in figure 1. RF transmitted by the cell-site (both control and voice channels) is received at the cell-site "donor" antenna D1 and passes through the

plexer to the forward preamplifier. This amplifies the signal and provides RF output to the 5 narrow-band "forward" boards (boards 1-5). Signals entering these boards first encounter a mixer/synthesizer. The signal is translated down to the 70 MHz IF where it is further filtered and amplified. The IF filter is one channel wide (30 kHz), allowing only the selected channel to be amplified. After passing through this filter, the signal is translated back up by another mixer/synthesizer. The two synthesizers are independent of each other, allowing the input and output frequencies to be different. The amplification in the path is controllable so that the overall gain can be adjusted between 70 and 120 dB. A microcontroller is included in the narrow-band boards to control outputs and monitor inputs. The signals coming out of the forward boards are then each fed to a 1-watt driver, followed by a standard 45-watt power amplifier. The PA outputs are combined in a 5-channel combiner.

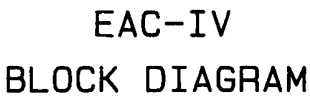


FIGURE 1

The reverse path through the system, starting with signals transmitted by the mobile and received at the M1 and M2 antennas is similar to the forward path. An important difference in the two paths, however, is in the output power capability. The forward path employs separate 45-watt cellular power amplifiers, while the reverse path signals are combined and amplified in a single 12-watt linear amplifier. This is because the donor cell-to-EAC-IV link is fixed and normally line-of-sight, where the path from the mobile is much more variable and not as reliable. To balance the system, higher power and diversity reception (to and from the mobiles) is used.

An 11th IF board, the Hand-Off/Locating board, is designed to receive from and transmit to the mobiles. It is not used to boost. The receive portion is used to scan the donor voice channels for mobiles that may be in need of repeating. The transmit portion is connected to a 1-watt driver and a 45-watt PA which is duplexed to antenna M2. Since this path is not combined, the hand-off/locating board can transmit with full power on any channel.

The remainder of the EAC-IV system supports the RF portions described above. The backplane board connects the RF boards to the Controller board, Mobile Interface board, and I/O board. These three boards contain mostly digital hardware and control the system.

EXTEND-A-CELL® IV FEATURES

Frequency Agility

On a competitive high power unit, the input frequency to each of the repeated channels is fixed. This requires sectorizing the donor cell-site or at least splitting several channels into a dedicated directional "link" antenna to provide signals to the repeater. This sectorization required at the donor cell is expensive, complex and significantly reduces the trunking efficiency of the donor cell.^[2]

The input side of the EAC-IV, however, is frequency agile. That is, the synthesizer is under software control and can instantaneously tune to any one of the donor cell frequencies. A scanning receiver monitors activity on all of the donor cell's receive frequencies (input to the system during set-up) to determine which mobile signals are candidates for boosting, and which signals should remain on or be sent back to the donor. Only the EAC-IV output frequencies are dedicated and must be determined by the cellular system engineer based on the system frequency plan.

SAT Fading Eliminated

Because the channels are translated to another frequency, allowable system gain can be much higher and the unit can be operated reliably at full-rated cell-site ERP. The most significant advantage

of voice channel translation, however, is the elimination of SAT fading. SAT is a high-frequency audio tone which is transmitted both by the mobile and cell-site transmitters. SAT acts much the same as tone squelch in conventional 2-way radio systems: when the proper tone is being received, the audio paths are turned ON. When SAT is lost, the audio is muted. With an on-channel or non-translating high-power booster, the signal from the cell-site can reach the mobile significantly earlier or later in time than the signal from the booster, causing phase cancellation of the SAT. This in turn causes muting of the received signal and an unhappy customer. This SAT fading cannot normally happen with low-power boosters, however, because of their limited RF range.

Diversity Receive

Another important feature of the EAC-IV is its diversity receive capability. Since two identical antennas are necessary to transmit the voice/control channel and the hand-off frequency control information, these antennas are also used to provide switched-diversity on receive. This means that the EAC-IV can have the same coverage capability as a cell site with balanced talk-out vs talk-back range.

Mobile Power Control

The EAC-IV has also implemented VMAC (Voice Mobile Attenuation Code) power control. When the mobile signal RSSI goes above a programmed threshold, the EAC-IV sends a 3-level power reduction step (each VMAC level is 4 dB, so this is equivalent to a 12 dB reduction). If the mobile signal subsequently goes below the hand-back threshold, the EAC-IV first increases the mobile power if it has been reduced. Hand-back will only occur at a pre-programmed level, usually VMAC 0, or full-power output.

THE HAND-OFF

Because the boosted voice channels are translated in frequency, a hand-off message must be received by the mobile terminal before it will change channels and operate on the translated frequencies. Even if the donor's signal does not overlap the EAC-IV coverage area at all, this hand-off message must be received by the mobile so that it will move from the donor channel to the translated voice channel within the SAT fade window. The EAC-IV generates this hand-off message on a sixth transmitter that momentarily operates on the donor transmit frequency.

FM Capture Effect

When there is coverage overlap of the donor and the EAC-IV, the FM "capture effect" is used to determine whether or not the mobile should be brought into the repeater. If the hand-off signal from the

EAC-IV is stronger than the donor's signal, the hand-off message captures the receiver and is decoded by the mobile which then changes frequency to the translated channel. If the mobile's received signal is stronger from the cell-site, the mobile will not respond to the hand-off message and the call will continue on the donor channel. The FM capture effect insures that the EAC-IV signal is at least 3 dB higher at the mobile terminal before successful hand-off.

CALL SCENARIOS

The following progression of events will help explain the call origination and hand-off sequences that occur with Extend-A-Cell IV.

Call Origination Within the EAC-IV Coverage Area

1. Cellular unit is locked onto the EAC-IV's translated control channel.
2. The subscriber initiates a call.
3. The call initiation data is received from the subscriber by the EAC-IV, translated and re-transmitted to the donor cell site.
4. The donor cell-site processes the call and sends a "go-to-voice-channel" message to the mobile on the control channel.
5. This is received (and decoded) by the EAC-IV, translated and re-transmitted to the mobile. The mobile changes frequency as directed and is now on one of the donor's voice channels.
6. The EAC-IV immediately initiates a hand-off message on this newly-assigned voice channel, directing the mobile to change frequency to one of its own voice channels.
7. If the signal from the EAC-IV is strong enough to capture the mobile's receiver, the mobile hands-off to the EAC-IV and the call continues as normal.
8. If for some reason the EAC-IV's hand-off message is not strong enough to capture the mobile receiver, the call continues as normal on the donor.

Hand-in

1. A cellular call is in-progress with the mobile located in the donor-cell coverage area.
2. The EAC-IV's scanning receiver recognizes that a signal level on one of the channels in its scan list has exceeded the hand-in threshold.
3. The EAC-IV sends a hand-off message on the mobile's voice receive channel, directing the mobile to change frequency to one of the EAC's voice channels. This voice channel is then activated in the EAC-IV to handle the call.
4. If the signal from the EAC-IV is strong enough

to capture the mobile's receiver, the mobile hands-off to the EAC-IV and the call continues as normal.

5. If the EAC-IV's hand-off message is not strong enough to capture the mobile receiver, the call continues on the donor. The EAC-IV recognizes that the hand-in was unsuccessful and shuts down the newly activated voice channel. This hand-in sequence is repeated a programmed number of times.

Hand-back

1. A cellular call is in-progress with the mobile in the EAC-IV coverage area.
2. The EAC-IV notices that the RSSI of a signal being repeated has gone below the hand-back threshold level.
3. The EAC-IV verifies that the mobile is operating at maximum VMAC and, if not, sends a message to increase power to maximum.
4. The EAC-IV sends a hand-off message on its forward voice channel directing the mobile to switch back to the donor voice channel.
5. The EAC-IV immediately sends another message attempting to return the mobile back to the same EAC voice channel it just left.
6. If the mobile is located in the donor-cell coverage area, then FM capture of the donor-cell should mask this second hand-off message and the donor-cell will continue to handle the call.
7. If the mobile is not located in the donor coverage area, the second hand-off will move the mobile back to the EAC. The call will continue through the EAC until the next hand-back attempt. Hand-back attempts will continue a programmed number of times. If all attempts fail, the EAC-IV keeps the call until the mobile disconnects or goes out of range.

APPLICATION CONSIDERATIONS

Because the EAC-IV is "transparent" and not recognized by the switch as part of the cellular system, hand-off's between the system and the EAC-IV are controlled by the EAC-IV. These hand-off's are normally possible only between the donor and the EAC-IV. This limits most applications to the periphery of metropolitan areas or rural areas.

It is possible, however, for the EAC-IV to scan donor-cell voice channels associated with any of the three possible SAT frequencies. This means that with proper design of the EAC link antenna systems, hand-in and hand-back is possible with multiple donor-cells. All calls initiated in the EAC-IV coverage area or handed-in from the primary donor-cell will only hand-back to that primary donor-cell. However, hand-in and subsequent hand-back is possible between the EAC-IV and other secondary donor-cells. Calls may not be handed back to any other donor

than the one from which they came. Also, the link antenna system must be designed to give approximately the same signal level from all the donor-cells involved.

Rural Applications

Several EAC-IV's may be run off a single central donor-cell to provide coverage like the spokes of a wheel around its hub. It is possible to construct a wide-area RSA system in this manner. This is particularly useful in areas where terrain features prevent good coverage from a single site, no matter how high the antennas are.

REMOTE CONTROL AND MONITORING

A most powerful feature of any Antenna Specialists Extend-A-Cell is the ability to remotely monitor and control its operation. It can even be programmed to call a particular telephone number and will give an alert of a critical alarm. Virtually all of the operating parameters are under software control. This monitor/control capability can be exercised locally through a serial link attached to a standard RS232, ASCII terminal. Extend-A-Cell comes equipped with a cellular mobile and installed Bell 212A / Bell 103 compatible modem, which allow remote dial-up access to the monitor/control capabilities of the unit.

Call History and Statistics

Besides the typical status and alarm monitoring, EAC-IV also provides comprehensive call history data and call statistics. The number of calls and the elapsed call time is logged hourly (5 a.m. to 10 p.m.) and displayed in a weekly format. This same format is used to show the number of times all channels are busy and the elapsed time they are all busy. Call statistics include the number of calls placed, received, handed-in, handed-back and lost for each channel. Not only is this data useful in analyzing traffic handled by the EAC-IV, but it can also be used to highlight certain hardware problems.

Real-Time Call Status Monitoring

An extremely useful feature is the ability to monitor the EAC-IV's operation in real-time. The display shows the channel pair in use, VMAC power step,

how the call entered the EAC-IV (call origination, mobile received or hand-in) and the mobile identification number (MIN) of units originating or receiving calls. Upon call termination it also shows the reason for termination. During this sequence it is also possible to monitor the power amplifier output power and board RSSI levels.

These supervisory features not only show what the unit is doing to help increase system revenue, but also indicate when more capacity may be needed.

NOVEL APPLICATIONS

Engineers in the field have found applications for the product that weren't even considered by the design group. For instance, the very first installation provided stand-alone cellular coverage in an area far-removed from the donor cell-site. This temporary installation was left in-place until a microwave link could be completed and a normal cell-site put on the air.

The most novel application, however, is an installation adjacent to the Canadian border in Michigan. An EAC-IV is transmitting a control channel in a case of "border protection." The problem was that the Canadian system control channel was stronger than the U.S. system in this border location. The U.S. signals were quite sufficient for coverage, but the mobiles would lock onto the Canadian control channel and roam in that system. A low-power broadband booster that had been installed did not provide a strong enough signal for the application. The EAC-IV was installed near the border and was configured to provide a translated control channel only. A bi-directional antenna system was installed to limit coverage to the U.S. side of the border. The application is working as desired.

CONCLUSION

EAC-IV is an example of what can result when innovative thought and common engineering principles are applied to solve a marketplace problem. These problems are quickly turned into opportunities not only for the manufacturer of the equipment, but also for the customers applying the equipment to their needs.

- [1] R. J. Jakubowski, "Propagation Considerations of Low-Power Cellular Boosters and Case Histories," 39th IEEE VTC Proceedings, pp 523-527.
- [2] F. Howat, "Cell-Like Performance Using the Remotely Controlled Cellular Transmitter," 39th IEEE VTC Proceedings, pp 535-540.