

Spec 200 Radio Code Line Ducting – Cause and Effect

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ABSTRACT

Spec 200 Radio Code Line Ducting – Cause and Effect

CSX Transportation has an extensive installation of Radio Code lines based on ATCS Spec 200. This implementation has been very successful with the exception of a problem caused by tropospheric ducting. During ducting events the radio code system becomes flooded with duplicate messages, which overloads the system causing code lines to fail. CSX has gained significant experience in controlling the effects of ducting events but lacked the understanding of why the system is impacted. We felt there was much to be learned about why the events had such a significant impact on the Radio Code system and how this might affect other applications. To answer this question and to learn more about the dynamics of the Radio Code system from the process control system to the field code line, CSX contracted with ARINC. ARINC has produced documents describing the dynamics of the system, impact and mitigation of ducting on the system, and specific design criteria to optimize the implementation of the ATCS technology. CSX Transportation's Train Control and CSX Technology's Communications Solutions departments are currently reviewing, planning, and implementing some of the recommended solutions.

INTRODUCTION

Radio based Code Line (RCL) is the most prevalent application to date of the Advanced Train Control System (ATCS™) Specification 200 communications protocol. RCL, when combined with other approaches such as coded track circuits and local metered power, has allowed railroads to retire wayside pole line, and has created the potential for a savings on recurring maintenance costs and an increase in reliability of code systems. The ability for wayside radio base stations to provide primary, secondary, and even tertiary coverage of control point locations does a great deal to minimize the effect of single base station outages.

CSX Transportation has implemented RCL to provide coverage for 3200 miles of track with 2410 miles in the Southeast. This includes over 240 BCPs and 1350 MCPs throughout the Eastern states. At the completion of the pole line elimination project we will provide RCL coverage for over 6000 miles of track.

CSXT has prioritized system availability and communications reliability and thus adopted a design strategy to deploy base stations (BCPs) such that they provide at least double coverage for each mobile (field) station (MCP). In addition, a strategy of connecting alternating base stations with multi-drop circuits minimizes the impact of a failure of any single circuit. Antenna heights have been standardized at 150 feet for BCPs and 75 feet for MCPs. These heights may vary to accommodate specific geographic conditions.

The RF ducting phenomena experienced by CSXT during 2000 has impacted the features designed to provide high availability of the network to the control point locations in such a manner as to actually induce failures. The end result of ducting effects are multiple code lines going into a code fail state, preventing dispatchers from requesting signals and turnouts, and thus severely impacting train operations.

Our research into this problem was triggered by a severe outage, which occurred on January 15, 2000. This ducting event caused disruption of service in Florida, Georgia, Alabama, South Carolina and North Carolina. The geographic pattern is consistent with the nature of the atmospheric conditions that are common in the Southeastern United States, which produce RF ducting. This ducting phenomenon is well known to many UHF broadcasters in the Southeast. RF ducting results in unusually extended UHF propagation along a north-south direction which, in CSXT's code line configuration, causes base stations to receive transmitted messages from control points not typically in range, often hundreds of miles away. A base station impacted by a ducting event may be receiving messages from many more control points than normal. The resultant number of duplicate messages per base station, times the number of base stations, plus the additional acknowledgement messages required by the protocol, offer a volume of traffic that seems to overwhelm network equipment and RF data links in CSXT's RCL configuration.

TERMS AND ACRONYMS

ATCS SM	Advanced Train Control Systems
BCP	Base Communications Package
CC	Cluster Controller
CSXT	CSX Transportation
MCP	Mobile Communications Package
RCL	Radio Code Line
RF	Radio Frequency
SSI	Signal Strength Indicator
UHF	Ultra-High Frequency

TACTICAL ACTIONS

During the January 2000, RF ducting event and subsequent events throughout the spring, we learned that the system flooded with data became overwhelmed to a point that it could not recover. Efforts to stop and restart Packet Switches would also fail since the startup and initialization sequences poured even more data into the system.

We learned that the ducting phenomena would cause the same data messages to be introduced into the system through as many as four or five BCPs. This volume of data could not be handled by the Packet Switch software causing the system to collapse.

Through a process of trial and error we found that by shutting down alternating BCPs the excess data traffic would subside enough for the system to recover. Safetran engineers determined that by monitoring the levels of internal buffers they could determine appropriate flow control limits and modulate the passage of data through the system. The combination of software modifications and the BCP amputation has allowed us to keep the system running through ducting events with little or no disruption of service.

CSX determined that it needed to seek a strategic solution to the effects of ducting even though it had established tactical response procedures. The objective of the strategic solution was to ensure the future reliability of CSX's radio code system, as well as the underlying ATCS Specification 200 radio system. Given that there was likely no "silver bullet" solution to mitigate the effects of RF ducting, CSX determined that the following were key to a strategic solution approach:

- Understanding of the current utilization and capacity of the radio code system's underlying ATCS Specification 200 RF and ground networks;
- understanding of the operating intricacies of the BCP, MCP, and Cluster controller equipment deployed and operating in CSX's radio code system, particularly related to Specification 200 compliance; and
- Understanding of the trade-off associated with adjustment of system design parameters, including RF coverage, message traffic, and timer values.

With this knowledge in-hand, CSX felt it would be ready and able to evaluate potential solutions. ARINC, Inc. was retained by CSX for a project to research and develop materials to support the objectives of understanding stated above. The project statement of work authored by CSX included tasks designed to collect information to support key initiatives. The process and results of major activities of the project are described below.

IDENTIFICATION OF POTENTIAL SPECIFICATION 200-BASED APPLICATIONS

CSX has, over time, identified a number of railroad applications that it could deploy that could utilize the Specification 200 network it has deployed for the radio code system. It was determined that an inventory of these potential applications, along with their feature set requirements would be of use when reviewing the merits of potential solutions to the effects of RF ducting. CSX has utilized the inventory of applications and associated network requirements to support its selection of optimal solutions. Any solution that enhanced or maintained the network's capability to support other application requirements would be viewed in a more favorable light than one that doesn't.

The potential Specification 200-based applications and associated network requirements identified by CSX included the following:

- Work order reporting
- Train document delivery
- Wayside infrastructure monitoring
- Locomotive health and location reporting
- MoW vehicle location reporting
- Data Defect detector results
- Positive Train Control
- Text messaging

After the inventory was completed, a profile of network requirements and attributes was developed for each application. The requirements and attributes were identified at a high-level, which was determined to be adequate for their intended use as supporting information for solutions to the problems experienced with the radio code system. The list of requirements and attributes was distilled down to those listed below:

- Traffic volume. The volume of traffic that the application would offer to the network.
- Traffic priority. The priority of the traffic that the application would offer to the network
- Traffic frequency. The frequency at which the application could offer traffic to the network. Some applications may be able to store and forward data, even large volumes, and still provide their associated benefits.
- Traffic Direction. The general direction in which most of the offered network traffic moves, e.g. mobile-to-office, office-to-mobile.
- Continuous coverage. Whether or not the application would require the ability to offer and receive traffic from the network at any location on the railroad. For example, many of the locomotive-based applications would require continuous (or near-continuous) coverage because they can operate at any point on the railroad. Additionally, those applications that require continuous coverage usually require the mobile tracking capability of the network.

A benefit of this analysis in addition to helping in the evaluation of potential solutions, is an understanding of how CSX's Specification 200 network is able to support these applications today.

CAUSE AND EFFECTS OF RF DUCTING ON THE RADIO CODE SYSTEM

CSX had plenty of evidence of the effects of the ducting on their radio code system – the inability to communicate to and from control point sites and error logs from the packet switch/cluster controller. An analysis into the root causes and effects was in order.

An academic review of the meteorological and climatological dependencies of the RF ducting phenomenon supported CSX's experiences. The coastal southeastern United States was particularly prone to ducting during late January 2000 due to its proximity to the Atlantic Ocean and the temperature and air movement patterns that existed at the time. The resultant ducting produced extremes in RF propagation along a generally north-south direction. This is consistent with CSX's observations at the time, during which BCP sites in Florida were observed to be in communication with MCP sites as far away as South Carolina at nominal signal strengths!

To collect data on effects of ducting on the radio code system, monitoring equipment and protocol analyzers were inserted at various points in CSX's ATCS network. The configuration of CSX's ATCS network and the monitoring equipment is depicted in Figure 1.

Access to the BCP diagnostic port provided the following information:

- RF message traffic received and sent via the BCP;
- Ground network message traffic received and sent via the BCP; and
- Identity of MCPs which were in communication with the BCP.

The protocol analyzer inserted between the modem and packet switch/cluster controller provided information about traffic through the whole "string" of BCPs on the multi-drop circuit, as well as

timing data for the BCP polling cycle. This data proved invaluable in understanding how the capabilities of the ground network effect overall network throughput and capacity.

In short, the data collected through the means described above coupled with analysis yielded insight into a sequence of events, which was inducing failures of the CSX radio code system.

That chain of events is as follows:

1. The right mix of weather conditions along the southeastern seaboard produces a RF duct.
2. The duct enhances RF propagation, resulting in exceptional propagation of BCP and MCP transmissions.
3. The exceptional propagation results in an increase in message traffic experienced by each MCP and BCP in the network.
4. The increased RF message traffic results in more collisions at each radio site and a significant increase in data offered to the ground network and packet switch/cluster controller.
5. The increase in traffic offered by the packet switch/cluster controller and BCPs exceeds the capacity of the ground network, resulting in BCP buffer overflows, lost messages, and resets. Additionally, contention on the RF channel limits the ability for code system messages to traverse the network with the time thresholds required by the code equipment.

A severe ducting event did not occur during the time that the monitoring equipment was in place. However, the data collected while the monitoring equipment was installed was used to produce a profile of the operation of the network that identified its susceptibility to ducting. Figure 2

represents the ground network traffic and capacity profile for one of CSX's radio code lines, which consists of 9600bps multi-drop leased circuit connected to 6 BCPs. The figure depicts the relationship between the HDLC polling rate, which decreases (per BCP) as the packet switch/cluster controller dwells longer at each BCP to "drain" the messages. ATCS Specification 200 allows up to 5 messages per polling cycle to be retrieved from a BCP.

In CSX's case, the ground network capacity is a function of the number of BCPs on a multi-drop circuit, as well as the bit rate supported on the circuit. This particular code line is operating at approximately 2/3 of capacity in the steady state when no severe RF ducting event is occurring. An increase of 50% in the number of MCPs heard by the BCPs on this code line, such as would result from ducting induced propagation, would generate traffic well over the capacity of the HDLC ground network link.

Another result of the analysis of the collected data showed increases and decreases in message traffic on a minute-by-minute basis with great regularity each day. Because these changes in message traffic seemed to be a function of the time of day, rather than increased control point code traffic, it appears that CSX's code systems experience some effect of RF ducting on a daily basis. When the increased message traffic does not exceed the capacities of the RF and ground network, and the field code unit keep alive timers do not exceed their thresholds, the effect can go unnoticed. Figure 3 represents the aggregate received message traffic from a string of BCPs on a particular code line at sunrise and as atmospheric changes occur. The graph was typical of that observed on a daily basis during mid-December 2000. Figure 3 depicts a different code line than the one represented in Figure 2.

EQUIPMENT COMPLIANCE WITH ATCS SPECIFICATION 200

CSX suspected that equipment performance and specification compliance issues could contribute to problems experienced during ducting events. In parallel with the data collection and traffic analysis described above, ARINC researched the degree of equipment compliance to ATCS Specification 200 in cooperation with the manufacturers of equipment installed in CSX's radio code system. Each of the Specification 200 requirements was reviewed for each type of equipment (MCP, BCP, and Packet Switch/Cluster Controller) for applicability to operation of the radio code system. Those specification items that are required for operation of the radio code system were identified. Additionally, those specification items that are critical to the operation of the other applications identified by CSX were also identified. A matrix of Specification 200 requirements was prepared and submitted to each equipment supplier for completion and a response. In addition to the responses, ARINC discussed equipment operation with each supplier to gain their thoughts on the problems experienced by CSX. The collected message data was also analyzed to identify potential anomalies in equipment operation. Situations in which a high volume of traffic exists will exercise the radio's queue and priority management.

An example of observed equipment operation that could negatively impact radio code system operation is performance of the BCP transmitter. In one instance, a BCP was observed to generate messages with duration in excess of that prescribed by the specification, which can result in more collisions and reduced performance on the RF link. Figure 4 depicts a decoded message transmitted by a BCP installed on CSX's radio code system.

Analysis of the decoded message resulted in the identification of two characteristics of this BCP, which could result in reduced network performance:

1. A synchronization bit duration far in excess of that prescribed by the specification. The specification defined 40-bit sync duration is on the order of 8ms, vs. 55ms in this sample.
2. A signal “trailer”, consisting of a series of sync bits and carrier, of 35ms which is not prescribed in the specification.

In this particular sample, the BCP occupies the RF channel for 82ms longer than the requirement of Specification 200. It should be noted that this particular BCP is of a fairly old hardware generation and that the limitations of the transmitter hardware and its ability to stabilize when keyed are possibly involved.

The product of this work was a specification compliance matrix for each vendor/product installed in CSX’s radio code system, along with a list of compliance and performance related issues observed from the sampled data.

RECOMMENDED SOLUTIONS

ARINC identified eleven potential solutions for CSX that it could implement to mitigate the effects of RF ducting on its radio code system. These potential solutions were developed based on the results of analysis of collected message traffic, the equipment supplier protocol compliance matrix responses, and observations and event log data provided by CSX. These potential solutions fell into four categories:

- Message traffic reduction. Two potential solutions identified configuration or software changes to equipment that would reduce the amount of traffic offered by the packet switch/cluster controller and field code unit to the RF network;
- Radio equipment configuration. Five potential solutions identified configuration and/or software changes to the radio equipment for better management and utilization of the RF channel;
- Ground network configuration. One potential solution identified a change to ground network configuration to increase capacity of the individual ground network links
- Radio coverage and power. Three potential solutions identified changes to radio coverage and transmitter power settings to potentially reduce the propagation of signals during ducting events.

A profile for each of the identified solutions was created. The purpose of this profile was to identify the key (and peripheral) issues that CSX should consider while evaluating the potential solutions for implementation. Information in the profile included the following:

- Expected technical benefit(s) provided by the solution, e.g. a reduction in message traffic, reduced RF collisions, reduced signal propagated through a RF duct, etc.
- Risks and operational impacts of the solution. Some potential solutions carried with them potential impacts and risks to CSX's radio code system, and thus to CSX's railroad operations.
- Cost elements incurred by the solution. These were identified to allow CSX to create a worksheet for developing the internal and external costs for implementation of the solution. An example internal cost element is that of sending maintainers to field radio sites; an

example external cost element is that cost quoted by a supplier to modify equipment hardware or software.

Finally, ARINC developed a high-level ranking of the eleven potential solutions based on the information contained in the profile for each solution. While the precise internal and external costs for each solution were not well defined at the time, previous experience with similar efforts and a good understanding of the benefits and risks were applied to evaluate the solutions.

Those solutions that offered a reduction in radio code system message traffic were generally seen to have the highest technical benefit to cost ratio. This was based on the facts that reduced message traffic produced benefits on both the RF and ground networks, created additional network capacity for other Specification 200 applications, and seemed to be achievable with manageable efforts on the part of CSX and its equipment suppliers.

The radio and ground equipment configuration solutions were generally seen to have acceptable technical benefit to cost ratios, but were often accompanied with significant risks and requirements for a large scale, highly coordinated cut over. An example of such is a change to BCPs and MCPs that would have to be executed in synchronized fashion over a large geographic area or several subdivisions.

Finally, the radio coverage and power solutions seemed to offer very little technical benefit. CSX's radio code system network has been engineered for high reliability and includes significant provision for secondary, and often tertiary BCP coverage of MCP sites. Deliberate

reduction in coverage was seen to severely impact the overall coverage and reliability engineered by CSX, with limited ability to reduce the amount of ducted signal strength.

SUMMARY

The CSX Train Control / Communications team met to review ARINC's list of recommendations for changes to the radio code line network. We had requested that ARINC present their recommendations in the order of expected improvement. Improvement was defined as a reduction in network traffic and a higher resistance to failures due to changing atmospheric conditions. The list included ARINC's recommended changes and their comments on the effectiveness of several CSX proposals. Each of the eleven recommendations listed was discussed with respect to expected improvement, risk, cost and dependencies. Individuals or sub-teams were assigned to develop preliminary implementation schedules and estimates of related costs for selected items. Several items on the list were placed "on hold" pending further review.

The implementation strategy was to work the list "top down" to achieve the highest incremental gain before moving on to the next recommendation. The combined effect of the top two recommendations was expected to achieve a 75% reduction in network traffic. It was assumed that some of the lowest rated recommendations would never need to be addressed. The exceptions were some proposed antenna changes that were already in progress when the ARINC report was received. We decided to proceed with those changes because the material was ordered and it would provide some reference test data for the CSX radio engineers to consider in future radio code line design projects.

The CSX team then scheduled a meeting with ARINC to discuss each recommendation in more detail and to consider the impact a proposed change might have if, or when, the use of the CSX network is expanded beyond radio code line. We held a round table discussion on ATCS Specification 200 protocol and on the expected operational characteristics of a typical radio code line system. One goal of the process was to determine areas of non-compliance in the current CSX network and develop a plan for correction.

We focused our discussion on a portion of the CSX network that has suffered the greatest impact from ducting events. The radio code line circuit that supports train operations on the Nahunta and Jesup Subdivisions consists of forty-seven control points extending from Hilliard, Florida to Savannah, Georgia. Each control point communicates through a local radio (MCP) to nearby base station radios (BCPs). Seven BCPs service this section of radio code line with additional coverage provided by BCPs on three adjacent code line circuits. The Nahunta and Jesup radio code line has secondary, and often tertiary, radio coverage for all control points. The initial design provided for secondary coverage and subsequent radio code line installations on adjacent Subdivisions have provided additional overlapping coverage. This code line is also in an area that is often subject to the weather conditions that foster ducting events. The ducting effect creates a significant change in radio signal propagation, which enables traffic between sites that do not normally communicate. This additional traffic is passed on to the ground network as well.

The first ARINC recommendation that we considered was changing the various timers in the radio code line system to reduce the number of network management messages sent over the RF

portion of the network. Depending on the signal equipment in place, the field code device's indication (or Ground Contact) timer is currently set at sixty, or ninety, seconds. Extending this time to one hundred and twenty seconds at all locations would significantly reduce the number of watchdog messages sent over the network. In the office, the packet switch timer currently puts a control point in "code fail" status if that control point fails to indicate for more than two and one-half minutes and this would be extended to four and one-half minutes. This would then be equal to twice the field code device timer duration (to allow for re-try) plus thirty seconds for data to get through the network to the packet switch. The two-minute difference in determining code fail at an individual control point was considered acceptable. The timer changes, alone, were expected to achieve a 50% reduction in message traffic.

Other timers associated with the radio code line system (in both the signal system equipment and in the MCP radios) would also be changed to improve network performance. Proposed timing changes would be reviewed with the appropriate manufacturer to identify any issues that may have been overlooked.

The next ARINC recommendation was that we employ another ATCS channel and place every other BCP of a radio code line circuit on that second channel. Implementing this alternate channel scheme would significantly reduce the amount of RF traffic received at each BCP under normal conditions and also mitigate the impact of undesired RF messages received during ducting events.

Currently all control point radios (MCPs) and base station radios (BCPs) on the CSX system operate on the same ATCS Channel (Channel 2). This has been considered beneficial in the past because it simplified installation and testing, and provided system redundancy by allowing control points to have an alternate message path through “secondary coverage”. Secondary coverage is achieved by designing radio code lines so that control points are always within range of two BCPs. If one BCP fails, the control point is still in communications with the dispatch center through the second BCP. The management systems at the dispatch center display the control points, and the primary, secondary, and tertiary (if applicable) BCP that services each control point. This can be done because each time a control point transmits a message, all BCPs within range receive it. The BCPs decode the control point address and signal strength and report this to the management system in the dispatch office. This also means, however, that every message transmitted from a control point is routed to the office at least twice through the multiple BCPs. When ducting occurs the message traffic is compounded by additional traffic from distant control points and results in a slow down and/or failure of the system.

The ARINC proposal to change the operating channel of every other BCP on a radio code line also requires modification of the equipment at each control point location. The MCP radios must be reconfigured to allow operation on multiple channels, and the signal equipment must be modified to issue channel change requests to the MCPs as required. The control point will attempt to communicate with the dispatch center for a specified period on its’ designated primary channel. If communications is unsuccessful for this period, the signal equipment will issue a channel change request to the MCP, and the MCP will switch to the secondary channel. Once again the control point will attempt to establish communications with the dispatch center for the

same time period. If successful, the control point will continue to operate on this second channel. If unsuccessful, the control point will revert to the primary channel and the process starts again.

The previously discussed timers at each control point, and in the packet switch at the dispatch center, also impact the alternate channel proposal. They are an important part of determining the optimum time for channel change to occur. It was decided that we should address the frequency change proposal in conjunction with the timer change proposal to avoid complications with the settings and to limit the number of field site visits required.

The major ducting events we have sustained, and the related operational impact of these events, have been painful for CSX but we have benefited from the experience. The initial meetings of the CSX Train Control / Communications team provided a forum for open discussion of the problems and a cooperative environment for developing solutions. We worked together to develop and implement mitigation schemes which have improved our ability to cope with subsequent ducting events and to keep the railroad operating.

Our discussions with ARINC have given us a new level of understanding of the elements of the Spec 200 protocol and of the feature set of the ATCS network design. In reviewing ARINC's analysis of the operation of individual components of our network, and in discussing these findings with the manufacturers of these products, we have identified and corrected a number of minor compliance issues. Individually, none of these represented a significant negative impact but correcting them has helped to optimize the overall network operation.

We are currently implementing, or preparing to implement several of the recommended changes.

The mitigation plan has allowed us to proceed cautiously and minimize risk. Some equipment issues still remain unresolved and we continue to pursue these with the appropriate manufacturers.

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FIGURES

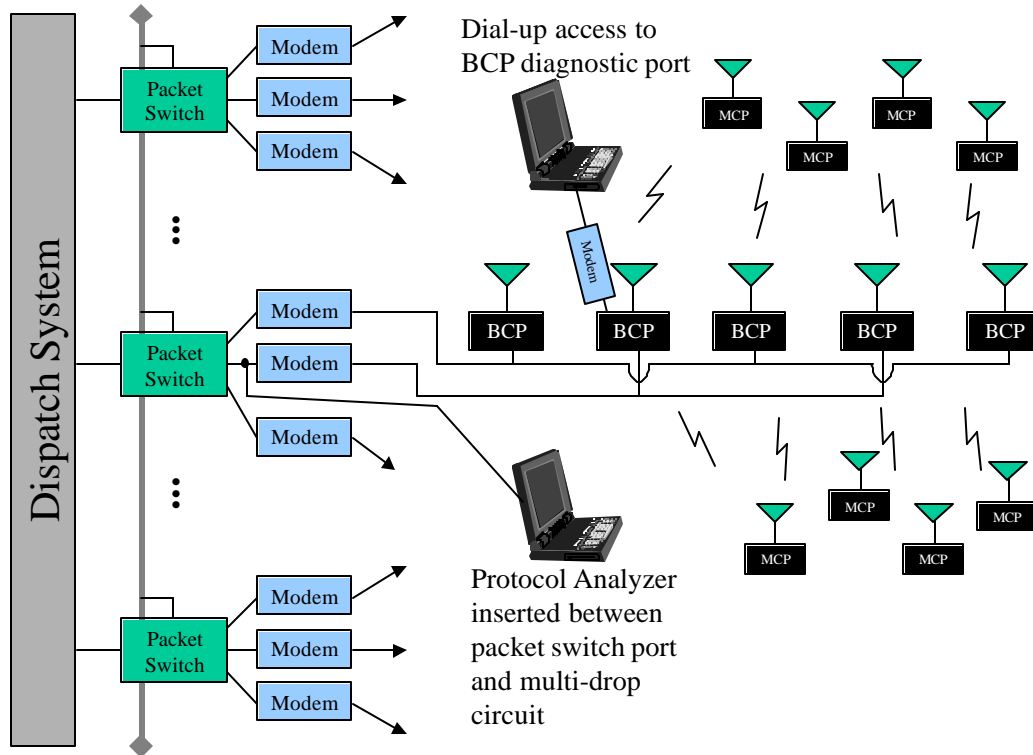


Figure 1: Configuration of Inserted Monitoring Equipment

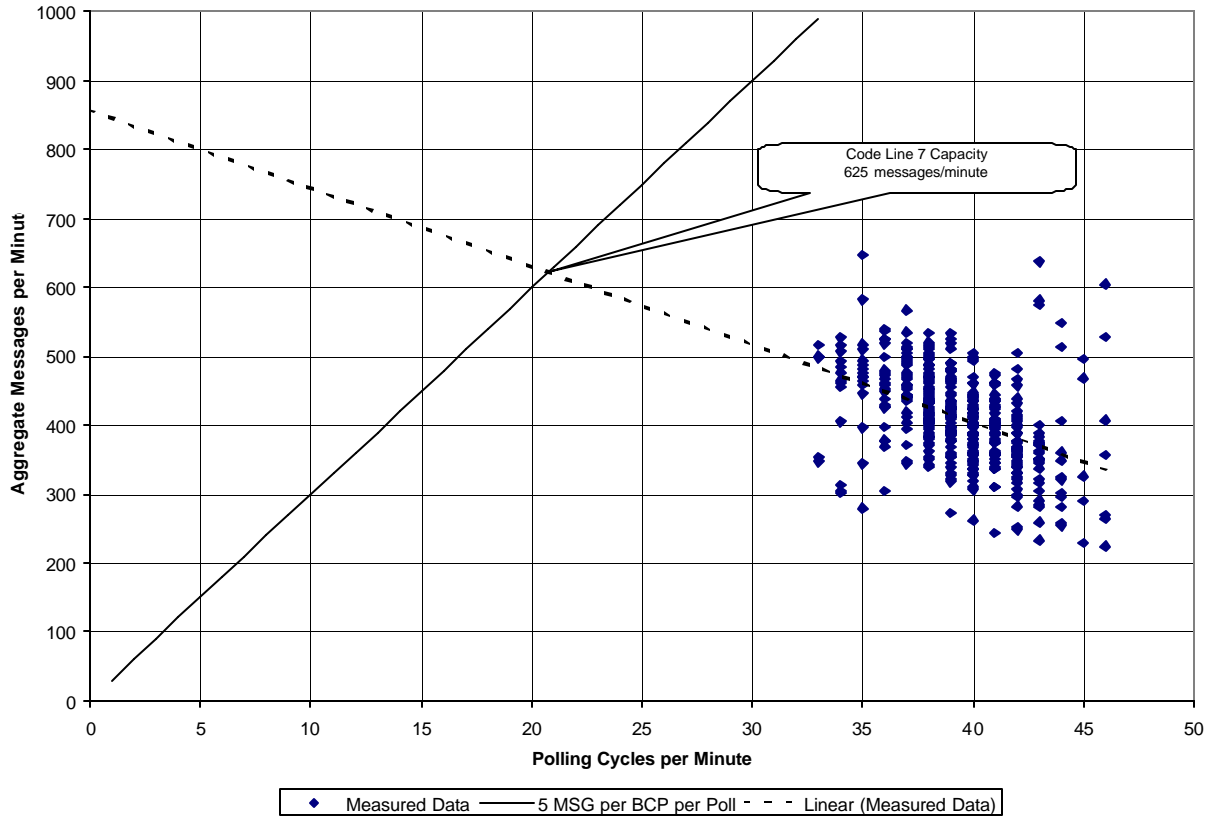


Figure 2: Code line Ground Network Utilization and Capacity

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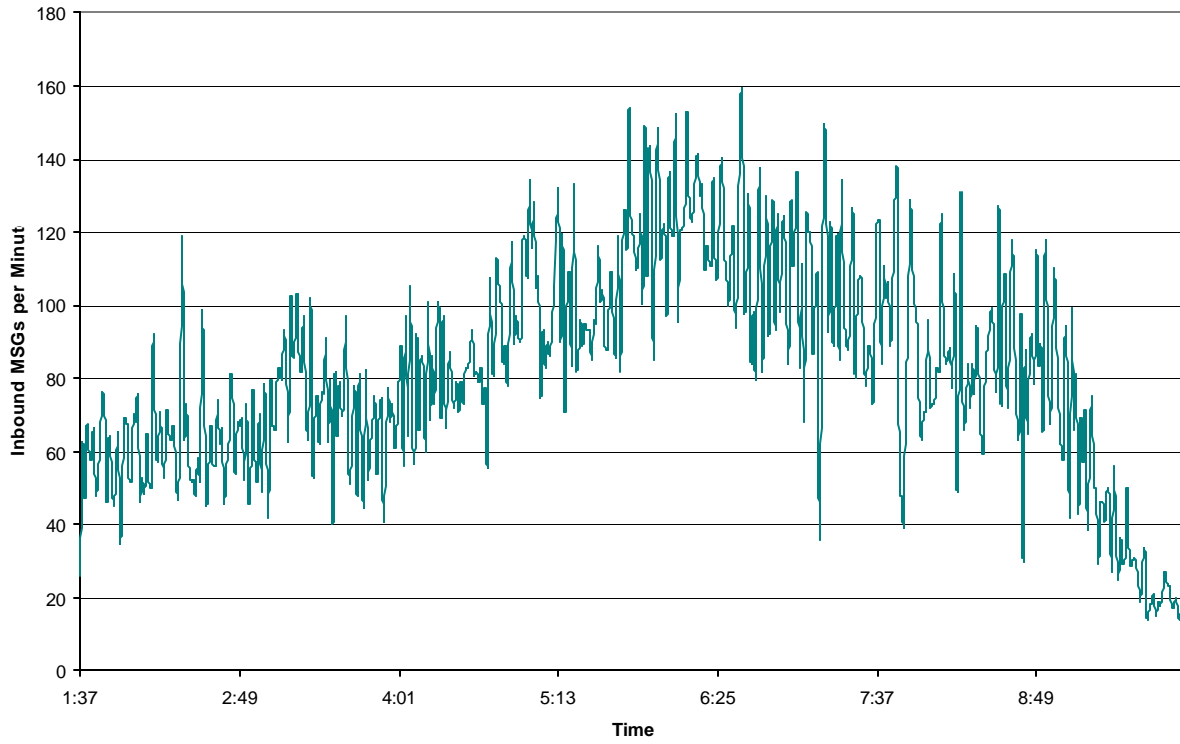


Figure 3: Code line Message Traffic

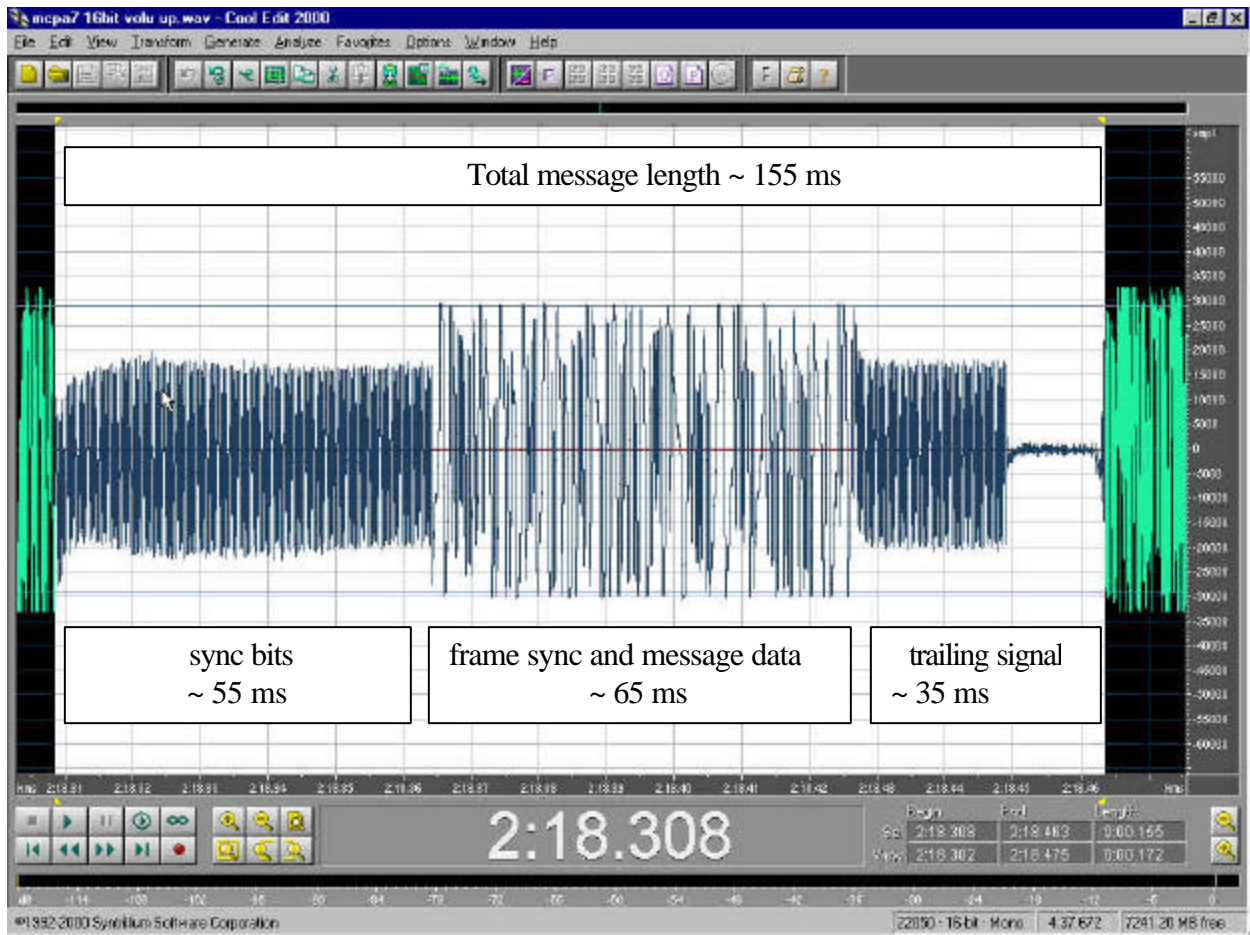


Figure 4: BCP Transmitted Message