ABR Technology Overview and Testing Challenges

Agilent Technologies Broadband Series Test System Application Note

Introduction

ATM was designed to handle a variety of services and applications such as video, voice, and data. Each of these applications has specific requirements for effective transfer across an ATM network. Based on this, it is vital that ATM traffic is controlled and managed so that quality of service guarantees can be made to each user.

To simplify the process and segment the various applications, a number of service classes were developed to handle various traffic classes differently based on their specific needs. By doing this effectively, network congestion can be minimized and network utilization maximized, therefore increasing the efficiency of the network and subsequently reducing the cost of service delivery.

This paper will focus specifically on the testing challenges for ATM switches capable of supporting ABR services. The challenges outlined in this paper are applicable for companies designing and manufacturing ATM switches and service providers responsible for verifying conforming ABR devices prior to installation and deployment.

ATM Forum Service Categories

The ATM Forum developed a number of different service categories based on the characteristics of different applications and traffic types.

Constant Bit Rate (CBR)

Intended for real time applications, such as voice and video, which require tightly constrained delay and delay variation. Peak Cell Rate (PCR), Cell Delay Variation (CDV), Cell Loss Ratio (CLR), Cell Transfer Delay (CTD) are used to define a Constant Bit Rate (CBR) service.

Variable Bit Rate Service (VBR)

Can be segmented into real-time and non-real-time services. VBR-rt is designed for real-time applications that transmit at a variety of rates. PCR, CDV, CLR, CTD, Sustained Cell Rate (SCR) and Burst Tolerance (BT) are used to define a VBR-rt service. PCR and CLR are used to define a VBR-nrt (non-real-time) service.

Unspecified Bit Rate (UBR)

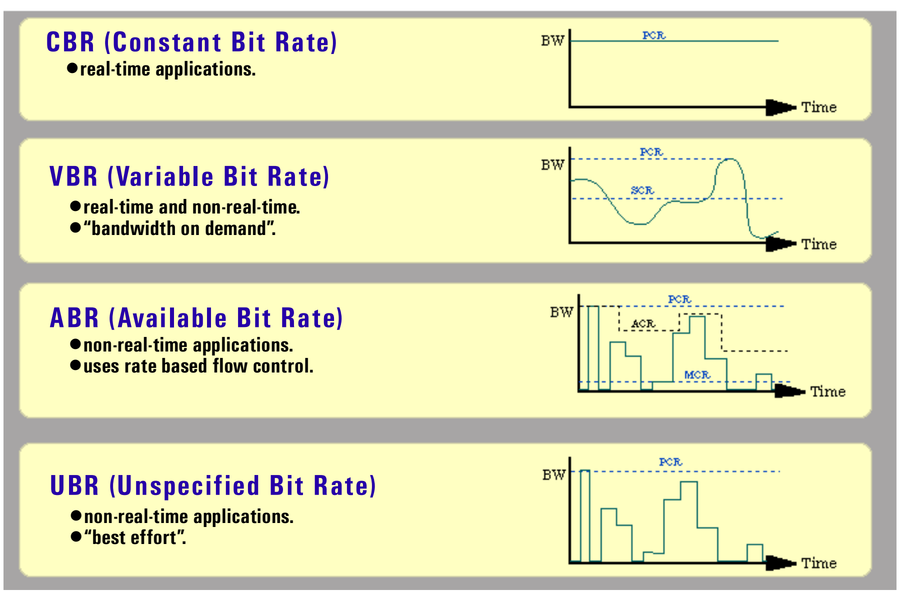
Designed for delay-tolerant and non-real-time applications.

Available Bit Rate (ABR)

Designed for applications that have the ability to adjust their transfer rate based on spare capacity in the network.

The ATM Forum is currently working on the revision to the Traffic Management specification. The new specification is expected to be completed by the end of 1998. One of the key additions proposed in the new specification is a new service category called “Guaranteed Frame Rate” (GFR).

This service class will sit between ABR and UBR in terms of priority and provide QoS guarantees at the frame level.



ATM Traffic Management Specifications

The ATM Forum and ITU-T have developed two specifications to manage traffic and help control network congestion.

ATM Forum Traffic Management 4.0 Specification

Developed in 1996, this specification covers ATM service architectures, ATM layer Quality of Service (QoS), traffic classes, connection admission control, policing/shaping, OAM, and procedures for traffic management. The various processes for implementing ABR are covered in this document.

ITU-T I.371 Traffic Control and Congestion Control in B-ISDN

This specification was developed after the ATM Forum specification in August 1996. A number of differences exist between this specification and the ATM Forum specification.

Both documents have specifications for the ABR service category.

ABR Service

The goal of the ABR service category is to provide rapid access to available unused bandwidth within the network. ABR services help to maximize the efficiency of the network and ensure that close to 100% of the network bandwidth is used most of the time.

ABR is ideal for applications that are not sensitive to time delays. ABR was originally designed for data transfer, as it is not time sensitive and cell loss can significantly impact retransmission rates. There are no cell delay guarantees for an ABR service.

As ABR does not guarantee a set amount of bandwidth over an extended period of time, the pricing of ABR will be significantly lower than CBR and VBR services. However, it will be more expensive than UBR services.

ABR uses flow control feedback mechanisms know as ABR Resource Management (RM) cells. These cells are transmitted regularly from the source to the destination. As they traverse the network, ATM switches update the cell about their ability to handle traffic. If the network elements can handle more or less traffic, the RM cell will be adjusted accordingly.

Acceptable levels of CLR are network-specific. The objective is to minimize cell loss, providing the network appropriately adjusts to the various ABR feedback mechanisms. An ABR service is described by minimum, peak, and allowed cell rates (MCR, PCR, ACR); and CLR.

TM4.0 Summary

Service Category (Traffic Class)	Policing & Traffic Shaping Parameters			Guaranteed QoS Parameters	
	PCR, CDVT (GCRA)	SCR, MBS (GCRA)	RM Flow Control	CLR, CMR, CER	CTD, CDV
CBR	X			X	X
VBR-rt	X	X		X	X
VBR-nrt	X	X		X	
ABR			X	X CLR Only	
UBR					

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How does ABR work?

Basic ABR services follow a fairly simple implementation procedure. The source requests a connection and establishes the ABR-specific parameters (MCR, PCR, ACR, CLR). The ACR value is not constant; it is updated continuously to reflect the rate at which the ABR source is currently allowed to schedule cells for transmission.

Once transmission begins, an ABR RM cell is transmitted into the network on a regular basis. This cell contains information about the PCR, MCR, and current ACR. As the RM cell passes through the various network elements it is updated to reflect the status of the network. The RM cell reaches the destination, which in turn transmits a backward RM cell to inform the source on any changes in transmission rates

ABR call initiation using UNI 4.0 signalling

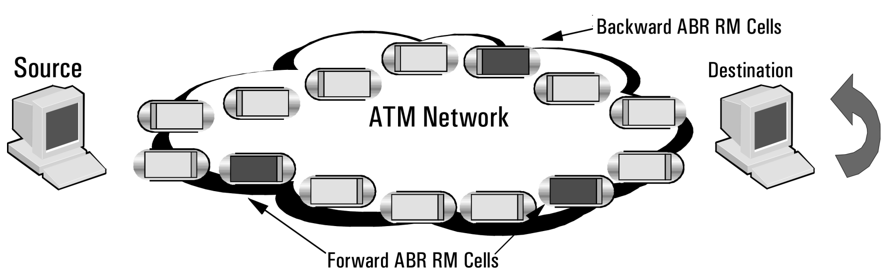
An ABR connection is established using the Q.2931 messages and procedures. Additional traffic parameters are added to various Q.2931 messages to support this transfer capability. A new information element (IE) is added to both *CONNECT* and *SETUP* messages. The purpose of the ABR *SETUP* IE is to specify the appropriate service category parameters during call connection admission control (CAC).

ABR call initiation parameters

A number of parameters are negotiated during the CAC process, including:

- Peak Cell Rate
- Minimum Cell Rate
- Rate Increase factor
- Rate Decrease Factor
- Initial Cell Rate
- Transient Buffer Exposure
- Fixed Round Trip Time

ABR Call Initiation Parameters	Description
Peak Cell Rate (PCR)	Must be specified by the calling party and may be negotiated downwards by other network elements.
Minimum Cell Rate (MCR)	Can be specified by the calling party. If not specified, the default is 0.
Rate Increase Factor (RIF)	Controls the amount by which the cell transmission rate may increase on the receipt of an RM cell.
Rate Decrease Factor (RDF)	Controls the decrease in the cell transmission rate.
Initial Cell Rate (ICR)	Rate at which a calling party should initially begin sending traffic.
Transient Buffer Exposure (TBE)	Negotiated number of transmitted cells a calling party is limited to until the first RM cell is received by the source.
Fixed Round Trip Time (FRTT)	Accumulated time it takes an RM cell to complete the entire feedback loop from source to destination and back to source.
Nrm	Nrm is the maximum number of cells a source may send for each forward RM-cell.
Trm	Trm provides an upper bound on the time between forward RM-cells for an active source.
ABR Decrease Time Factor (ADTF)	The time permitted between sending RM-cells before the rate is decreased to ICR.



ABR flow control occurs between source end-systems and destination end-systems.

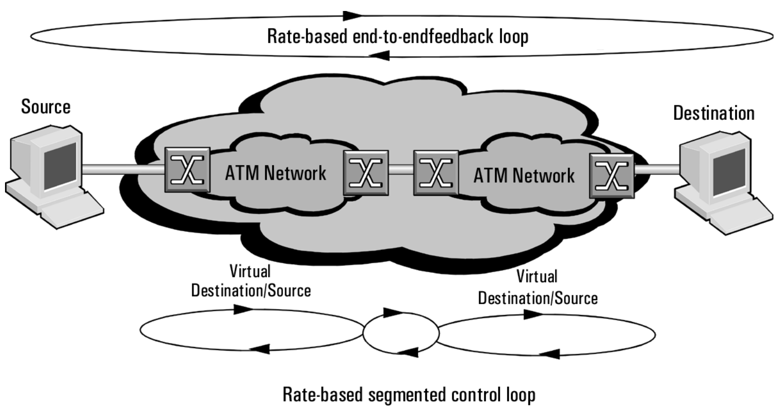
ABR flow control

ABR flow control occurs between the source and the destination and is bi-directional. ABR RM cells can either be forward (source to destination) or backward (destination to source). The flow of forward and backward ABR RM cells forms a control loop that adjusts the flow of ABR traffic.

A network element may:

Directly insert feedback control information into RM cells when they pass in the forward or backward direction.

Indirectly inform the source about congestion by setting the EFCI bit in the data cell header of the cells of the forward information flow. The destination will update the backward RM cells to notify the source if further rate adjustments are required.



End-to-end versus segmented rate-based control loops for ABR services.

End-to-end versus segmented control loops

Rate-based control is generally preferred to credit-based control. It allows the bandwidth of the connection to be controlled more efficiently because the cell transmission rate is directly linked to the amount of bandwidth consumed.

ABR rate-based control loops can be split into 2 categories:

- End-to-end feedback loop
- Segmented control loop

End-to-End Feedback Loop

One feedback loop exists for the entire network and ABR RM cells (both forward and backward) traverse the entire length of the network, with each network element providing information about congestion and network utilization.

Segmented Control Loops

A network may be divided into a number of segmented RM cell feedback loops. Each segmented loop acts like a complete “end-to-end” feedback loop. Segmented loops are optional and are based on virtual sources and virtual destinations.

Segmentation may be desirable at administrative boundaries. For example:

- between two different carrier ATM networks
- when the magnitude of round-trip delay differs between two segments

ABR RM cell structure

In-rate and out-of-rate cell types

An ABR RM cell can be either in-rate or out-of-rate. *In-rate* RM cells have the CLP bit equal to 0 and cannot be transmitted above the ACR. They are transmitted as part of the normal feedback loop process. *Out-of-rate* RM cells are used to make an increase request for ABR connections that have an ACR equal to 0.

ABR congestion control

An ABR service can handle congestion in a number of different ways:

- EFCI bit marking
- Relative rate (RR) marking
- Explicit rate (ER) marking
- Virtual source/virtual destination (VS/VD) control

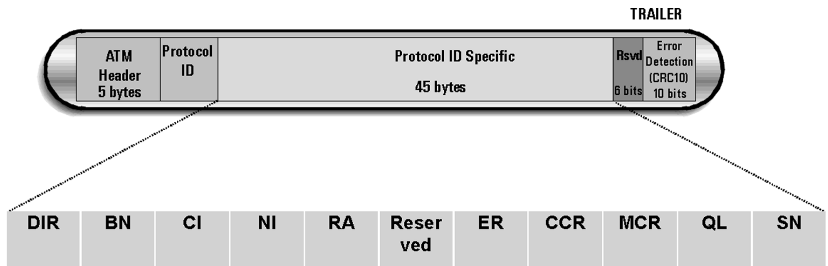
EFCI bit marking

A network element may set the Explicit Forward Congestion Indication (EFCI) bit in the ATM cell header to indicate congestion. EFCI only flows from source to destination.

After receiving a cell with EFCI equal to 1, the destination will change the Congestion Indication (CI) field in the next backward RM cell. When the source receives this cell, it will adjust the ACR. The level of adjustment is calculated by multiplying the current ACR by the Rate Decrease Factor (RDF).

The RDF value is a defined during the CAC process. One of the weaknesses of EFCI control is that it cannot adjust the RDF to suit the specific needs of the network.

The source will adjust its rate to the newly-calculated ACR value. If the modified ACR value is less than the MCR, it will be set to the MCR value.

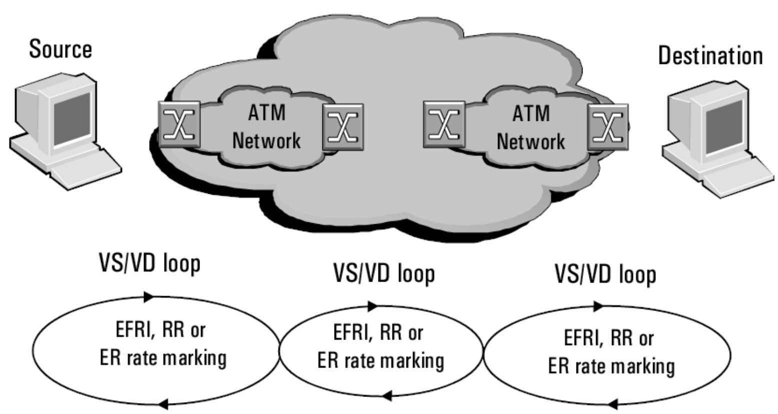


DIR	RM-cell direction (forward or backward)	**Reserved**	Reserved
BN	BECN Cell	**ER**	Explicit Cell Rate
CI	Congestion Indication	**CCR**	Current Cell Rate
NI	No Increase	**MCR**	Minimum Cell Rate
RA	Request/Acknowledge	**QL**	Queue Length
		SN	Sequence Number

ABR RM cell structure

ABR Congestion Control Methods

Rate Marking Method	Forward Indication	Backward Indication
EFCI	EFCI bit in user cell header	CI bit in RM cell
Relative Rate (RR)	CI bit in RM cell	CI or NI bits in RM cell
Explicit Rate (ER)	CI bit in RM cell	ER bit in RM cell



ABR VS/VD congestion control using either EFCI, RR, or ER rate marking.

Relative rate marking

Relative rate marking is a process that uses forward and backward ABR RM

cells. Depending on the level of congestion, an ATM network element can adjust the CI bit or the No Increase (NI) bit. When the CI bit is equal to 1, the process of adjusting traffic is the same as described for EFCI bit marking when EFCI is equal to 1.

If the NI field is set to 1, the source is not allowed to increase the rate of transmission.

Explicit Rate Marking

A network element may set the Explicit Cell Rate (ER) bit to reduce the source ACR to a specific value. The ER value is requested by the source, usually equal to the PCR. It may need to be reduced, to suit network conditions.

The advantage of ER rate marking is that it identifies a specific rate to reduce to during congestion. This minimizes overreaction by the source and reduces feedback-loop settling times.

A disadvantage of ER control is that it provides coarse rate adjustment. RR control offers finer rate adjustment, at the expense of slower reaction times.

Virtual source/virtual destination control

The Virtual Source/Virtual Destination control process divides an ABR connection into two or more separately controlled segments. By doing this, congestion can be managed at a micro level using the three other ABR congestion control methods. The MCR extends across all VS/VD boundaries. By dividing the ABR connection up into a number of segments, the network can react more quickly and specifically to localized areas of congestion.

An example of an ABR control loop

The following points explain a typical flow for negotiating, connecting, transmitting and controlling an ABR connection:

1. The source creates an ABR connection with a call *SETUP* request:
   - Values for ABR specific parameters are identified.
   - Lower/upper bounds on the source rate are requested.
2. The connection is then established.
3. The cell transmission begins:
   - The rate at which an ABR source is allowed to schedule cells for transmission is denoted by an ACR.
   - The ACR is initially set to the ICR (Initial Cell Rate) and is always bounded by the MCR and the PCR.
   - Transmission of data cells is preceded by the sending of an ABR RM cell.
   - The source will send RM cells, typically after every Nrm user cells transmitted, and more frequently when the ACR is low.
4. The ABR loopback control procedure begins:
   - The source copies the rate at which it is allowed to transmit cells (ACR) into the CCR field of the RM cell.
   - The source copies the rate at which it wishes to transmit cells (usually PCR) into the ER field.
   - Switches in the forward path can decide to reduce the value in the ER field, or set the CI bit to 1.
   - Switches supporting only the EFCI mechanism will ignore the content of the RM cell.
   - RM cells generated by a switch must have the BN bit set to 1, and either the CI or NI bit set to 1.

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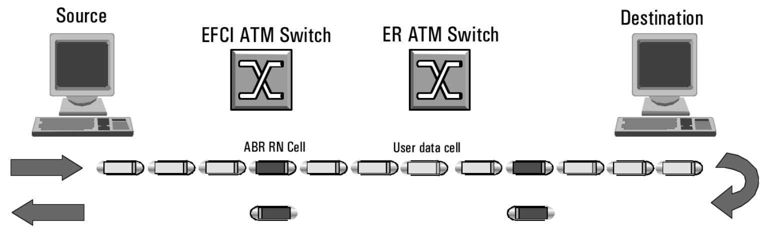
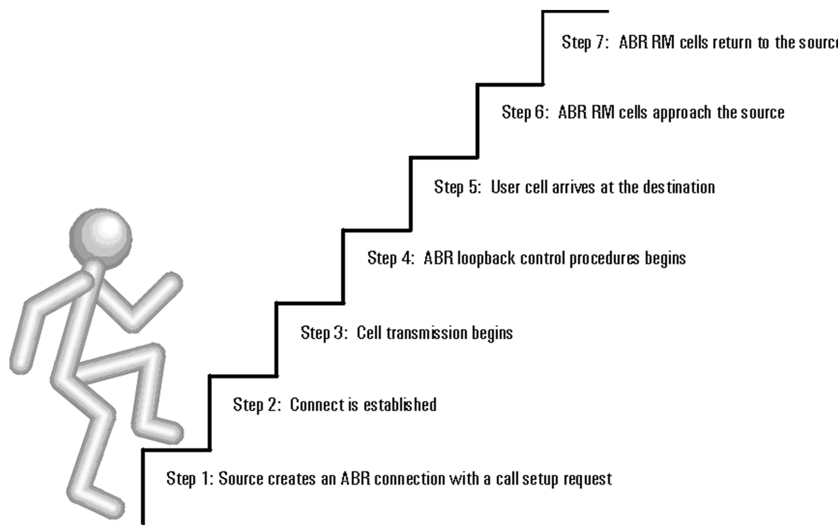
Tag, control, return



a: The source sends RM cells after 'n' user data cells.
b: Upon congestion EFCI switches set EFCI in forward data cells.
c: The destination monitors EFCIs, adjusts the rate in the RM cells and returns them to the source.

An example of the ABR flow model.



The flow control steps to establishing, sustaining and throttling ABR flows.

5. The user cell arrives at the destination:
   - Destinations should change the direction bit in the RM cell and return the cell to the source.
   - If the destination cannot support the rate in the ER field, it reduces the ER to a value that it can support.
   - If the destination has seen an EFCI since the last RM cell was returned, it should set the next RM cell's CI bit to 1.
6. The ABR RM cells approach the source:
   - Each switch in the backward path may examine the cell to determine if it can support the ER for this connection.
   - If the ER is too high, the switch will reduce it to a value it can support.
   - The switch should never increase the ER.
   - Switches should modify the ER content of the RM cells on either forward or backward journeys, but not on both.
7. The ABR RM cells return to the source:
   - The source should reset its ACR based on the information carried by the returning RM cell.
   - If the CI bit is not set, then the source may increase the ACR up to the ER value returned (never exceeding the PCR).
   - If the CI bit is set, then the source must decrease its ACR to a fraction of its current ACR.
   - If the ACR is still greater than the returned ER, the source must decrease its ACR to the returned ER value (never below the MCR).
   - If the NI bit is set, the source must observe the CI and ER fields in the RM cell, but must not increase the ACR above its current value.

ABR Futures: Point-to-Multipoint

The ATM Forum has not yet specified Point-to-Multipoint ABR connections. However, there has been some reference made to this in the ATM Forum's Traffic Management 4.0 specification. Each branch of the Point-to-Multipoint connection is considered as a point-to-point connection. The Minimum Cell Rate (MCR) must be equal across all branches. One area that needs to be determined by the ATM Forum is how to consolidate the feedback from each branch and present the information to the source in one consolidated format.

ABR Testing Challenges

Testing ABR switches

The logical sequence when testing and deploying ABR devices is to perform three types of tests:

- functional
- conformance
- performance

Functional testing

Functional testing is used to describe those tests which determine if a protocol or group of protocols function correctly. Functional testing can be as simple as testing correct RM-cell implementation or can be as complex as testing interworking between network elements. Functional testing is crucial in order to ensure conformance to standards and applicable ABR source/destination roles.

There are many functional areas that need to be tested for correct implementation of ABR capable switches including:

- ABR source/destination behavior
- RM cell processing
- congestion marking
- SVC ABR connection admission

There are a number of key functional test objectives when it comes to designing and verifying ABR devices.

Fundamental to ABR testing is the premise that each of the ABR sources, destinations, and associated network elements implement and deliver ABR services correctly.

ABR is a real-time protocol and its ability to change to the dynamic needs of the network is essential. Testing a switch's ability to tag and police the various ABR connections is critical to maintaining the agreed QoS of all services running on the network in a *fair* and *fast* manner.

It is with these broad objectives in mind that the following questions and test scenarios aim to answer.

Test Scenario #1

ABR Functional Test: Stimulus/response and congestion management

The objective of this test scenario is to verify that the switch notifies ABR sources of imminent congestion, and to see if congestion can be avoided.

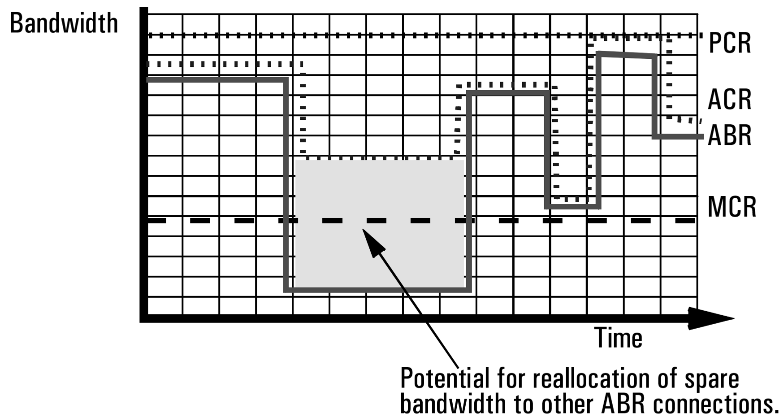
In this example, the ABR tester needs to emulate both the source and destination end-stations. CBR and ABR connections are established with the combined PCRs of both services exceeding the available link bandwidth. The ABR service's MCR and the CBR service's PCR must not exceed the total link bandwidth.

A number of measurements need to be taken to analyze how the switch handles congestion:

- invalid RM cell count
- forward/backward RM cell count
- user cell count
- user cell loss

Questions to consider when analyzing ABR devices or systems include:

- *Did the ABR source adjust the transmission rate to the required value?*
- *What cell loss occurred and how much?*
- *Were Backward RM cells generated and were they transmitted quickly?*
- *What congestion control method was used and how effective was it?*



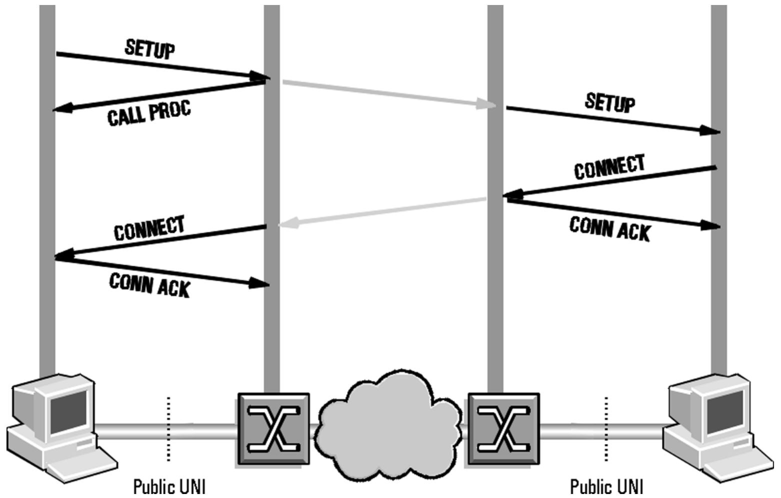
Objectives of this functional test are: ensure that the ATM switch correctly manages traffic priorities; verify that the switch notifies ABR sources of imminent congestion; and verify that the switch removes bandwidth from ABR sources at their ACR.

Simulation conditions may include:

- Generate background CBR, VBR, or UBR profiles.
- Vary the NRM value.
- Toggle the source flow above/below PCR.
- Establish a non-conforming ABR connection by changing the transmission rate above the ACR.
- Test under-utilized sources by specifying the transmission rate below the ACR.
- Test for various combinations of ABR source profiles.
- Generate user cells with CLP-1 (invalid in TM4.0).
- Generate tagged RM cells (not specified in TM4.0).
- Test with multiport load generation and ABR connections across multiple streams and ports.

Key results and measurements will include:

- Transmit line utilization.
- Receive line utilization.
- Invalid ABR RM cell count.
- Backward ABR RM cell count.
- User cell count (bandwidth).
- User cell loss (expect a low CLR for the ABR connection).
- Examine captured traffic to detect modification to RM cells (switch marking).
- Examine captured user cells to detect modifications to the CLP bit.
- Correlate measurements from both directions to determine loop and device reaction times.
- Measure source/destination reaction times with/without congestion.
- Measure intermediate switch reaction times with/without congestion.
- Measure total loop response time with/without congestion.
- Compare VS/VD loop response times between different segments.



Objectives of this functional test are to verify that the switch is capable of creating an ABR SVC connection; correctly negotiates the requested ABR parameters; correctly connects and clears ABR connections according to the CAC algorithm.

Test Scenario #2

ABR Functional test: SVC connection admission control (CAC)

This test focuses on the mappings between the firmware and hardware designs on the device. First a functional SVC ABR test should be completed, followed by a performance test to investigate how many SVC connections can be established and released simultaneously; and the maximum number of active ABR connections.

An ABR SVC connection is established using the ATM Forum's UNI Signalling 4.0 specification. In this test scenario, we will answer several questions:

- *Can the switch establish an ABR SVC connection with the requested ABR parameters?*
- *Can the switch correctly connect and tear down the connection?*
- *If the requested ABR parameters cannot be met, can the switch begin to transmit at the negotiated rate?*

For this test, a combination of signalling and ABR test capabilities are required. To determine if a switch is capable of setting up an ABR SVC connection, you will need to repeat the test with different combinations of the ABR service parameters: PCR, MCR, ICR, TBE, FRTT, RDF, and RIF.

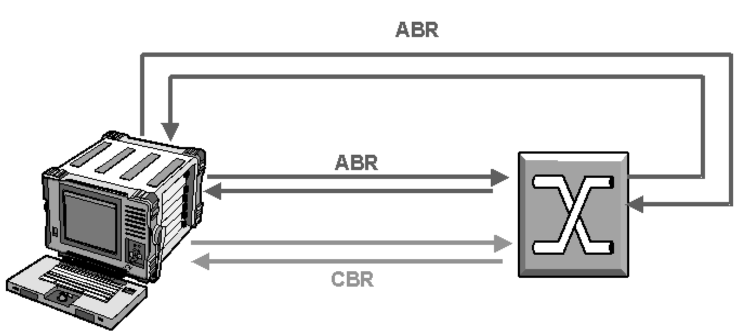
You will first need to establish whether the call has been connected or rejected. If connected, you should then determine how the negotiated ABR parameters differ from the values requested. Experimentation with varying parameters will test the CAC algorithm of the switch.

Simulation conditions may include:

- Establish a single SVC ABR connection.
- Establish a single SVC ABR connection at the same time as stressing the switch's SVC processor by establishing and releasing many other SVC connections on the same port.
- Establish an ABR connection with MCR -0 and ensure that the CAC function does not block the request.
- Establish point-to-point connections.

Key results and measurements will include:

- Compare the requested ABR parameters with those actually granted by the switch fabric.
- Analyze the fair allocation of switch/network resources.
- Measure the number of setup/releases that switch fabric can sustain.
- Measure the maximum number of active connections per port with guaranteed QoS.



Dual-port testing of ABR and CBR congestion and fairness

Functional ABR Testing

The BSTS ABR solution

Some of the test examples in this application note demonstrate the comprehensive functional ABR test capabilities now available on the Agilent Broadband Series Test System (BSTS).

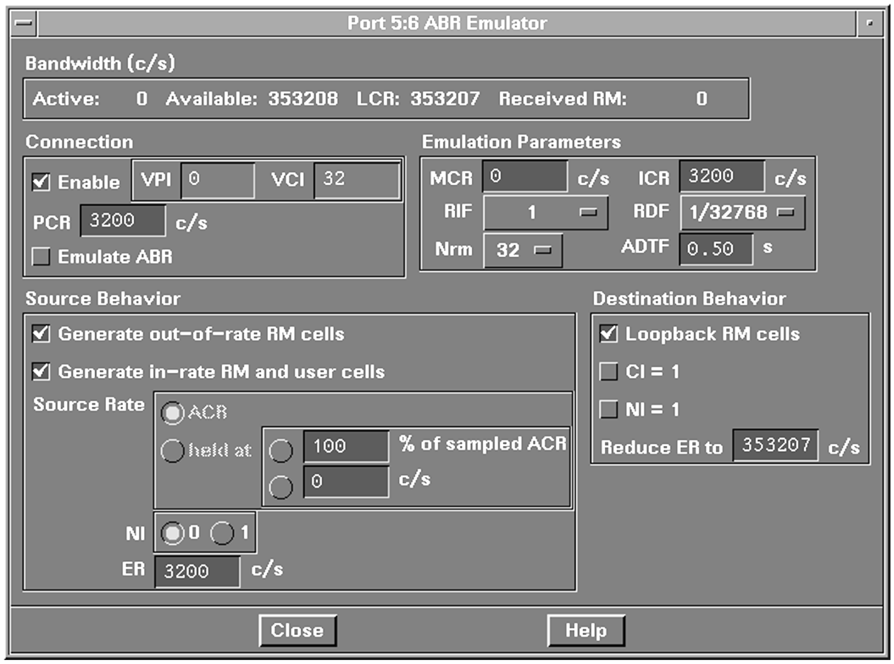
Agilent E6287A ABR Emulator

The Agilent E6287A ABR Emulator works with other BSTS ATM modules to support the full range of ATM Forum’s Traffic Management 4.0 (TM4.0) specification.

The BSTS ABR solution allows you to generate ABR traffic at rates up to 149.76 Mb/s, decode resource management (RM) cells, and analyze ABR flows. You can setup an SVC ABR connection and test a switch's ability to correctly negotiate, connect, transport, and clear ABR calls using the E4209A/B Cell Protocol Processor (CPP).

A range of measurements are available to determine the functional attributes of an ABR connection including cell loss, cell error and RM cell errors using the line interface or Agilent E4209A/B CPP. The ABR Emulator can work with existing BSTS ATM Line Interfaces from T1/E1 to OC-12c/STM-4c rates.

To complete a comprehensive TM4.0 conformance test you will need to emulate various scenarios that specify a range of services running over CBR, VBR, UBR and ABR connections. The ABR Emulator can be used in conjunction with the Agilent E1609A 0-622 Mb/s ATM Stream Processor to provide the complete TM4.0 multistream/multichannel stimulus/response ATM traffic solution over T1/E1 to OC-12c/STM-4c rates.



Main control panel of the Agilent E6287A ABR Emulator module.

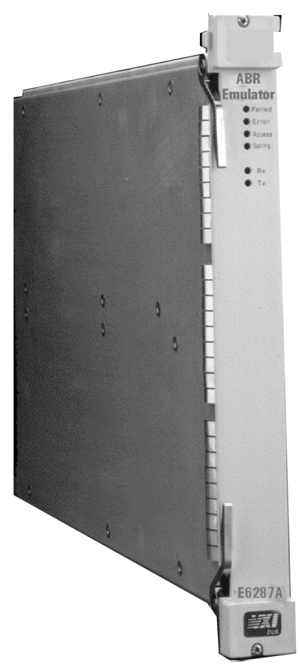
The ABR Emulator supports all four varieties of ABR flow control as defined in ATMF TM4.0 including:

- EFCI marking
- Relative rate
- Explicit rate
- VS/VD control

Associated BSTS products

The following associated BSTS products should also be considered a part of your ABR solution:

- E4209B Cell Protocol Processor (CPP)
- E4214B UNI Signalling Test Software
- E4223A Policing and Traffic Characterization Test Software
- E1609A 0-622 Mb/s ATM Stream Processor



Agilent E6287A ABR Emulator.

Acronyms

ABR	Available Bit Rate
ACR	Allowed Cell Rate
ADTF	ABR Decrease Time Factor
ATM	Asynchronous Transfer Mode
BN	Backward Notification
BSTS	Broadband Series Test System
BT	Burst Tolerance
CAC	Connection Admission Control
CBR	Constant Bit Rate
CCR	Current Cell Rate
CDF	Cutoff Decrease Factor
CDV	Cell Delay Variation
CER	Cell Error Ratio
CI	Congestion Indication
CLP	Cell Loss Priority
CLR	Cell Loss Ratio
CMR	Cell Misinsertion Rate
CTD	Cell Transfer Delay
CPP	E4209B Cell Protocol Processor
ER	Explicit Cell Rate
EFCI	Explicit Forward Congestion Indication
FRTT	Fixed Round Trip Time
GCRA	Generic Cell Rate Algorithm
GFR	Guaranteed Frame Rate
ICR	Initial Cell Rate
IE	Information Element
ITU-T	International Telecommunications Union
MCR	Minimum Cell Rate
NI	No Increase
PCR	Peak Cell Rate
PVC	Permanent Virtual Channel
QoS	Quality of Service
RDF	Rate Decrease Factor
RIF	Rate Increase Factor
RM	Resource Management
SCR	Sustained Cell Rate
SVC	Switched Virtual Circuit
TBE	Transient Buffer Exposure
TM	Traffic Management
UBR	Unspecified Bit Rate
VBR	Variable Bit Rate
VBR-nrt	VBR Non Real-Time
VBR-rt	VBR Real-Time

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Agilent Technologies Broadband Series Test System

The Agilent Technologies BSTS is the industry-standard ATM/BISDN test system for R&D engineering, product development, field trials and QA testing. The latest leading edge, innovative solutions help you lead the fast-packet revolution and reshape tomorrow's networks. It offers a wide range of applications:

- ATM traffic management and signalling
- Packet over SONET/SDH (POS)
- switch/router interworking and performance
- third generation wireless tesing
- complete, automated conformance testing

The BSTS is modular to grow with your testing needs. Because we build all BSTS products without shortcuts according to full specifications, you'll catch problems other test equipment may not detect.

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United States:

Agilent Technologies
Test and Measurement Call Center
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1-800-452-4844

Canada:

Agilent Technologies Canada Inc.
5150 Spectrum Way
Mississauga, Ontario
L4W 5G1
1-877-894-4414

Europe:

Agilent Technologies
European Marketing Organisation
P.O. Box 999
1180 AZ Amstelveen
The Netherlands
(31 20) 547-9999

Japan:

Agilent Technologies Japan Ltd.
Measurement Assistance Center
9-1, Takakura-Cho, Hachioji-Shi,
Tokyo 192-8510, Japan
Tel: (81) 426-56-7832
Fax: (81) 426-56-7840

Latin America:

Agilent Technologies
Latin American Region Headquarters
5200 Blue Lagoon Drive, Suite #950
Miami, Florida 33126
U.S.A.
Tel: (305) 267-4245
Fax: (305) 267-4286

Asia Pacific:

Agilent Technologies
19/F, Cityplaza One, 1111 King's Road,
Taikoo Shing, Hong Kong, SAR
Tel: (852) 2599-7889
Fax: (852) 2506-9233

Australia/New Zealand:

Agilent Technologies Australia Pty Ltd
347 Burwood Highway
Forest Hill, Victoria 3131
Tel: 1-800-629-485 (Australia)
Fax: (61-3) 9272-0749
Tel: 0-800-738-378 (New Zealand)
Fax: (64-4) 802-6881

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