IBIS

APPLICATION NOTES QAN-106

IBIS APPLICATION NOTES

What is IBIS?
I I/O
B BUFFER
I INFORMATION
S SPECIFICATION

IBIS is an approved standard within the Electronic Industry Alliance (EIA), and is also known as ANSI/EIA-656. IBIS is considered a behavioral model specification. An IBIS behavioral model contains I-V and V-T data of input and output buffers of a device in ASCII-text format. This data, along with keywords specified by the IBIS standard, can be used to describe the analog behavior of the device under operation. However, IBIS really isn't a "model", rather it is data that will be used by a simulator to create a behavior model of the device based upon certain algorithms. An IBIS behavioral model is sometimes referred to as an "IBIS file" or "IBIS datasheet". IBIS files are most commonly used for signal integrity simulations of high-speed boards or systems.

IBIS models are intended to be used for signal integrity analysis on systems boards. These models allow system designers to simulate and therefore foresee fundamental signal integrity concerns in the transmission line that connects different devices. Potential problems that can be analyzed by means of the simulations include the degree of energy reflected back to the driver from the wave that reaches the receiver due to mismatched impedance in the line; crosstalk; ground and power bounce; overshoot; undershoot; and line termination analysis, among others.

The IBIS specification supports several types of inputs and outputs that can be modeled three-state, open collector, open drain, I/O, and ECL, for example. The first step is to identify the different types of inputs and outputs on the device and determine how many buffer designs are present. It should be noted that one model can be used to represent more than one input or output in an IBIS file. However, separate models are required if the C_Comp and package parameters are different.

Package Parameters

R_Pin, L_Pin, and C_Pin are the electrical characteristics of resistance, inductance, and capacitance for each pin-to-buffer connection. The R_Pkg, L_Pkg, and C_Pkg are the lumped values for the overall package. As for the C_Comp parameter, the largest values are listed as max values and the smallest values are listed as min values.

The IBIS model configured the load and R/L/C values of packaging. The following R/L/C for Q-Tech QT625 are shown below:

```
[Package]
| variable   typ   min   max
R_pkg  1.000E-02  1.000E-02  1.000E-02
L_pkg  1.788E-09  6.682E-11  4.370E-09
C_pkg  3.728E-13  1.393E-14  9.110E-13
```

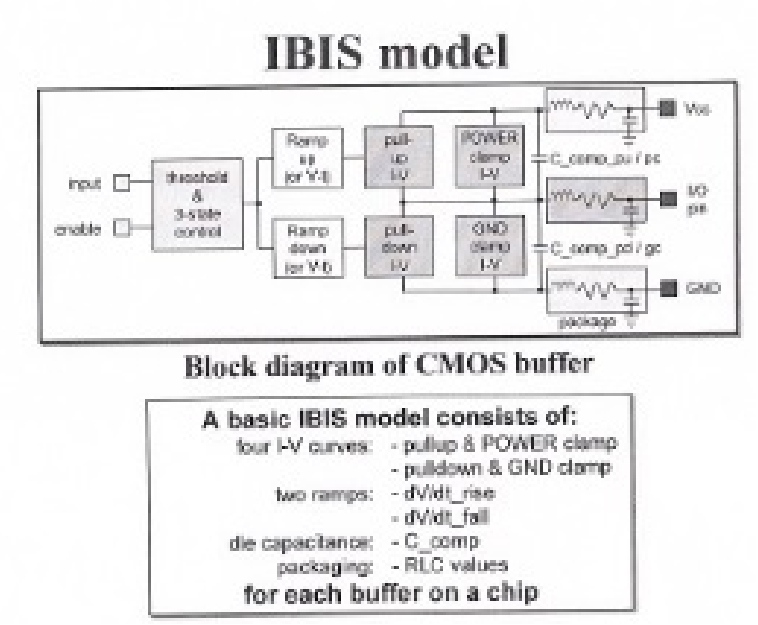
The IBIS model configured the load and R/L/C values of packaging. The following R/L/C for Q-Tech QT625 are shown below:

```
[Package QT606]
| variable   typ   min   max
R_pkg  1.000E-02  1.000E-02  1.000E-02
L_pkg  3.240E-09  3.240E-09  3.240E-09
C_pkg  1.510E-12  1.510E-12  1.510E-12
```

C_Comp

This is the silicon die capacitance and does not account for package capacitance. It is the capacitance seen when looking from the pad back into the buffer. C_Comp is a key parameter, especially for receiver inputs. C_Comp should have a value for each of the different corners, min, typ, and max. The largest value of C_Comp will be under the max corner, and the smallest value will be under the min corner.

C-Comp 1.48E-12 typical, 1.48E-12 minimum, 1.48E-12 maximum



Described simply, an IBIS model is a collection of DC (current versus voltage) and transient (voltage versus time) data taken from the device being modeled. This data can be collected through either laboratory measurement or by simulation of the SPICE model representing the device. Once created, the IBIS model can then be used by EDA tools to create a behavioral model of that device. The behavioral modeling process is proprietary to the EDA tool, and is based on the information contained in the IBIS model itself.

To model an output buffer within IBIS, the DC and transient data should include a pull-up curve, pull-down curve, rising waveforms, and falling waveforms. Once this data is collected through SPICE simulation, it will be formatted and included in the IBIS model representing the output buffer being modeled.
The pull-up and pull-down curves are defined by the I/V characteristics of the output buffer when it is fully in the logic high state, and logic low state, respectively.
The rising and falling waveform data describe the V/t characteristics of the output buffer. A ramped input stimulus is used to drive the output to a logic high for the rising waveforms and to a logic low for falling waveforms. In each case, voltage vs. time data is gathered.

HOW TO GENERATE AN IBIS MODEL?

IBIS models can be obtained by gathering data in simulations, or from bench measurements. If the former method is chosen, SPICE can be used to run the simulations and collect the V/I and V/T data for each of the input/output buffers. This allows process corner data to be included in the models. Then, using one of the SPICE-to-IBIS conversion programs available from the IBIS website, the IBIS model can be generated from SPICE.

The models can be generated for three different corner conditions: typical, minimum, and maximum. In a typical model, the data will be obtained for nominal supply voltage, nominal temperature, and nominal process parameters; in a minimum model, the data will be obtained with the lowest supply voltage, high temperature, and weak process parameters; and for a maximum model, the conditions will be the highest supply voltage, low temperature, and strong process parameters.

Each of these conditions leads to typical, slow, and fast models. A fast model is created by considering the highest current values with the fast transition time and the minimum package characteristics. On the other hand, the lowest current values with a slow transition time and maximum package values will produce a slow model.

If the data is obtained from lab measurements, then the model will be dependent on the characteristics of the device. If the device were a nominal device, a typical model would be obtained.
Once the data is collected, it is put into a file formatted in human-readable, ASCII text.

Figure 1 below illustrates an example of output waveforms of a 125MHz comparison between laboratory test results and HPSICE simulation using IBIS results simulation.

Figure 2. Q output waveform obtained from the laboratory measurement
(CF5035ALB, V_{DD}=1.8V, f=125MHz, C_L=15pF)

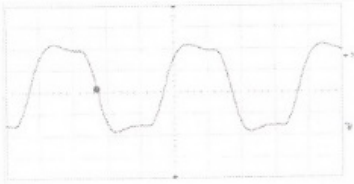


Figure 3. Q output waveform obtained from the Hspice simulation
using IBIS model "5035_18ab.ibs"

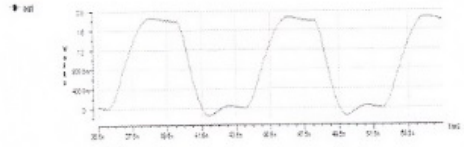


Figure 1

There is a margin of error between the output waveforms by HSPICE used at IBIS model generating the actual output waveforms.

The following sections shows an IBIS of a QT88LD9M-66MHz using a 2µm CMOS FACT technology

Teraspeed (R) Labs.

[File Name] qt88ld9m-66MHz.ibs

[File Rev] 3.0

[Source] Teraspeed (R) Labs.

[Date] 08-04-2009

[Notes] Quality Check of this IBIS model: Model Passes IBIS Check

Model parses into ICX IS. Simulation done with Hyperlynx.

1. MIN TYP MAX information is based on Temperature and Voltage characteristics only.

2. Package data gained using Tektronix IConnect Software.

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[Component] QT88LD9M

[Manufacturer] Q-TECH

[Package]

| variable typ min max

R_pkg 1.000E-02 1.000E-02 1.000E-02

L_pkg 4.490E-09 4.490E-09 4.490E-09

C_pkg 1.380E-12 1.380E-12 1.380E-1

[Pin] signal_name model_name R_pin L_pin C_pin

1 ENA inp_sh 1.000E-02 4.490E-09 1.380E-12

2 GND GND 1.000E-02 4.490E-09 1.380E-12

3 OUTPUT out_tri 1.000E-02 4.490E-09 1.380E-12

4 VCC POWER 1.000E-02 4.490E-09 1.380E-1

[Model] inp_sh

Model_type Input

Vinl = 800.000mV

Vinh = 2.00000V

C_comp 1.40000pF 1.39000pF 1.43000pF

| variable typ min max

[Voltage Range] 3.30000V 3.00000V 3.60000V

[POWER Clamp Reference] 3.30000V 3.00000V 3.60000V

[GND Clamp Reference] 0.00000V 0.00000V 0.00000V

[Temperature Range] 25 125 -55

[GND Clamp]

-3.30000V -460.235mA -445.686mA -504.121mA

-850.000mV -15.2826mA -25.0549mA -7.07504mA

-800.000mV -6.20189mA -16.4706mA -1.97196mA

-750.000mV -1.82636mA -7.88630mA -396.801uA

-700.000mV -423.092uA -3.06956mA -142.685uA

-650.000mV -155.200uA -1.01194mA -137.022uA

-600.000mV -144.689uA -279.691uA -131.359uA

-550.000mV -134.179uA -118.078uA -125.696uA

-350.000mV -92.1353uA -86.9112uA -103.043uA

-325.000mV -86.8799uA -83.0153uA -102.383uA

-275.000mV -85.5478uA -75.2235uA -101.062uA

6.60000V 97.6088uA 101.175uA 80.5553u

[POWER Clamp]

6.60000V 0.00000A 0.00000A 0.00000A

-125.000mV 0.00000A 0.00000A 0.00000A

-250.000mV 0.00000A 0.00000A 4.06259uA

-300.000mV 0.00000A 0.00000A 6.77098uA

-325.000mV 0.00000A 0.00000A 8.12518uA

-350.000mV 7.01772uA 0.00000A 9.47938uA

-400.000mV 21.0531uA 0.00000A 12.1878uA

-450.000mV 35.0885uA 14.2214uA 14.8962uA

-475.000mV 42.1062uA 28.4428uA 16.2504uA

-500.000mV 49.1238uA 42.6641uA 17.6046uA

-550.000mV 63.1592uA 71.1069uA 20.3129uA

-650.000mV 91.2300uA 485.174uA 25.7298uA

-700.000mV 281.326uA 1.11553mA 84.6930uA

-750.000mV 753.031uA 2.37121mA 274.787uA

-800.000mV 1.95363mA 5.42168mA 809.363uA

-850.000mV 5.02183mA 11.6290mA 2.26820mA

-900.000mV 10.8568mA 23.1293mA 6.41102mA

-950.000mV 23.2099mA 34.6297mA 14.9392mA

-1.00000V 35.5630mA 46.1301mA 27.8211mA

-1.05000V 47.9160mA 57.6304mA 40.7029mA

-1.10000V 60.2692mA 69.1308mA 53.5848mA

-1.15000V 72.6222mA 80.6311mA 66.4666mA

-1.20000V 84.9753mA 92.1315mA 79.3486mA

-1.25000V 97.3284mA 103.632mA 92.2305mA

-3.30000V 603.805mA 575.147mA 620.387m

[Model] out_tri

Model_type 3-state

Vref=0.000E+00

Rref=1.000E+06

Cref=3.000E-11

Vmeas=1.650E+00

C_comp 2.380E-12 2.330E-12 2.400E-12

[Voltage Range] 3.300E+00 3.000E+00 3.600E+00

[POWER Clamp Reference] 3.300E+00 3.000E+00 3.600E+00

[GND Clamp Reference] 0.000E+00 0.000E+00 0.000E+00

[Pullup Reference] 3.300E+00 3.000E+00 3.600E+00

[Pulldown Reference] 0.000E+00 0.000E+00 0.000E+00

[Temperature Range] 25 125 -55

[GND Clamp]

-3.3000E+00 -8.422806E-01 -9.083302E-01 -7.983312E-01

-1.0200E+00 -8.059485E-02 -1.130693E-01 -4.122071E-02

-1.0000E+00 -7.285760E-02 -1.061413E-01 -3.537088E-02

-9.6000E-01 -5.709443E-02 -9.217230E-02 -2.043065E-02

-9.2000E-01 -4.160231E-02 -7.827950E-02 -8.904507E-03

-9.0000E-01 -3.400130E-02 -7.122190E-02 -4.994983E-03

-8.8000E-01 -2.666456E-02 -6.401363E-02 -2.363537E-03

-8.4000E-01 -1.374790E-02 -4.905920E-02 -1.355913E-04

-8.2000E-01 -8.742140E-03 -4.139391E-02 0.000000E+00

-8.0000E-01 -4.991687E-03 -3.380940E-02 0.000000E+00

-7.8000E-01 -2.464811E-03 -2.657151E-02 0.000000E+00

-7.6000E-01 -9.601542E-04 -1.998693E-02 0.000000E+00

-7.4000E-01 -2.252240E-04 -1.435410E-02 0.000000E+00

-7.2000E-01 -2.775558E-17 -9.855259E-03 0.000000E+00

-7.0000E-01 0.000000E+00 -4.991687E-03 0.000000E+00

-6.8000E-01 0.000000E+00 -2.464811E-03 0.000000E+00

-6.4000E-01 0.000000E+00 -9.601542E-04 0.000000E+00

-6.2000E-01 0.000000E+00 -2.252240E-04 0.000000E+00

-6.0000E-01 0.000000E+00 0.000000E+00 0.000000E+00

-5.8000E-01 0.000000E+00 0.000000E+00 0.000000E+00

-5.0000E-01 0.000000E+00 0.000000E+00 0.000000E+00

-4.6000E-01 0.000000E+00 0.000000E+00 0.000000E+00

-2.6000E-01 0.000000E+00 0.000000E+00 0.000000E+00

-1.8000E-01 0.000000E+00 0.000000E+00 0.000000E+00

6.60000E+00 0.000000E+00 0.000000E+00 0.000000E+00

[Power Clamp]

-3.3000E+00 1.468368E+00 1.876474E+00 1.178876E+00

-1.0000E+00 1.071307E-01 1.683774E-01 7.456792E-02

-9.8000E-01 9.606281E-02 1.531726E-01 6.598065E-02

-9.4000E-01 7.073123E-02 1.233171E-01 4.458730E-02

-9.2000E-01 5.914158E-02 1.090284E-01 3.537468E-02

-9.0000E-01 4.892708E-02 9.532037E-02 2.780562E-02

-8.8000E-01 4.027082E-02 8.229917E-02 2.189120E-02

-8.6000E-01 3.300961E-02 7.009363E-02 1.746241E-02

-8.4000E-01 2.683450E-02 5.884339E-02 1.428590E-02

-8.2000E-01 2.168653E-02 4.867152E-02 1.209876E-02

-8.0000E-01 1.765983E-02 3.969891E-02 1.061381E-02

-7.8000E-01 1.465614E-02 3.205155E-02 9.571091E-03

-7.6000E-01 1.245499E-02 2.577454E-02 8.795249E-03

-7.4000E-01 1.085945E-02 2.077883E-02 8.178691E-03

-7.2000E-01 9.692495E-03 1.683604E-02 7.653853E-03

-7.0000E-01 8.801392E-03 1.365202E-02 7.188627E-03

-6.6000E-01 7.432636E-03 9.073520E-03 6.346794E-03

-6.2000E-01 6.367770E-03 6.494855E-03 5.641405E-03

-6.0000E-01 5.879542E-03 5.656005E-03 5.411861E-03

-5.8000E-01 5.416934E-03 4.993329E-03 5.263974E-03

-5.4000E-01 4.580893E-03 3.953678E-03 4.897458E-03

-5.0000E-01 3.818332E-03 3.090145E-03 4.193468E-03

-4.8000E-01 3.525176E-03 2.711590E-03 3.868100E-03

-3.8000E-01 2.402544E-03 1.228833E-03 2.202997E-03

-3.4000E-01 1.833239E-03 8.262908E-04 1.604287E-03

-2.2000E-01 4.476193E-04 3.368245E-04 2.253965E-04

-1.8000E-01 1.270432E-04 8.891848E-05 8.091121E-06

-1.6000E-01 3.469447E-18 0.000000E+00 3.469447E-18

6.6000E+00 0.000000E+00 0.000000E+00 0.000000E+00

[Pullup]

-3.3000E+00 4.769274E-01 3.940789E-01 5.648158E-01

-1.0000E+00 1.445234E-01 1.194178E-01 1.711563E-01

-9.8000E-01 1.416330E-01 1.170295E-01 1.677332E-01

-9.4000E-01 1.358520E-01 1.122528E-01 1.608869E-01

-9.2000E-01 1.329616E-01 1.098644E-01 1.574638E-01

-9.0000E-01 1.300711E-01 1.074761E-01 1.540407E-01

-8.8000E-01	1.271806E-01	1.050877E-01	1.506175E-01
-8.6000E-01	1.242901E-01	1.026993E-01	1.471944E-01
-8.4000E-01	1.213997E-01	1.003110E-01	1.437713E-01
-8.2000E-01	1.185092E-01	9.792262E-02	1.403481E-01
-8.0000E-01	1.156188E-01	9.553427E-02	1.369250E-01
-7.8000E-01	1.127283E-01	9.314591E-02	1.335019E-01
-7.6000E-01	1.098378E-01	9.075756E-02	1.300788E-01
-7.4000E-01	1.069474E-01	8.836921E-02	1.266556E-01
-7.2000E-01	1.040569E-01	8.598085E-02	1.232325E-01
-7.0000E-01	1.011664E-01	8.359250E-02	1.198094E-01
-6.6000E-01	9.538549E-02	7.881579E-02	1.129632E-01
-6.2000E-01	8.960452E-02	7.403905E-02	1.061169E-01
-6.0000E-01	8.671405E-02	7.165069E-02	1.026937E-01
-5.8000E-01	8.382359E-02	6.926234E-02	9.927063E-02
-5.4000E-01	7.804266E-02	6.448563E-02	9.242438E-02
-5.0000E-01	7.226172E-02	5.970892E-02	8.557814E-02
-4.8000E-01	6.937126E-02	5.732057E-02	8.215502E-02
-3.8000E-01	5.491893E-02	4.537879E-02	6.503940E-02
-3.4000E-01	4.913796E-02	4.060206E-02	5.819312E-02
-2.2000E-01	3.179516E-02	2.627193E-02	3.765439E-02
-1.8000E-01	2.601423E-02	2.149522E-02	3.080814E-02
-1.6000E-01	2.312376E-02	1.910687E-02	2.738502E-02
0.0000E+00	0.000000E+00	0.000000E+00	0.000000E+00

8.0000E-02	-1.098005E-02	-9.029415E-03	-1.356474E-02
1.8000E-01	-2.520806E-02	-1.970515E-02	-3.037019E-02
2.0000E-01	-2.795502E-02	-2.196513E-02	-3.355198E-02
2.6000E-01	-3.577358E-02	-2.850257E-02	-4.284880E-02
2.8000E-01	-3.832636E-02	-3.054166E-02	-4.579242E-02
3.2000E-01	-4.335613E-02	-3.454252E-02	-5.142108E-02
3.8000E-01	-5.062991E-02	-4.038941E-02	-6.015255E-02
4.2000E-01	-5.530202E-02	-4.419181E-02	-6.591663E-02
4.6000E-01	-5.968997E-02	-4.788292E-02	-7.155947E-02
5.0000E-01	-6.409024E-02	-5.143656E-02	-7.705456E-02
5.8000E-01	-7.287438E-02	-5.814829E-02	-8.773016E-02
6.0000E-01	-7.500315E-02	-5.971514E-02	-9.029504E-02
7.0000E-01	-8.524737E-02	-6.750765E-02	-1.025074E-01
7.2000E-01	-8.720726E-02	-6.903660E-02	-1.047994E-01
7.6000E-01	-9.102724E-02	-7.207459E-02	-1.092047E-01
8.2000E-01	-9.650875E-02	-7.638611E-02	-1.158794E-01
8.4000E-01	-9.825601E-02	-7.777080E-02	-1.180597E-01
9.6000E-01	-1.079439E-01	-8.561822E-02	-1.304139E-01
1.0600E+00	-1.156931E-01	-9.126368E-02	-1.398151E-01
1.0800E+00	-1.171435E-01	-9.236022E-02	-1.415950E-01
1.1600E+00	-1.225991E-01	-9.658503E-02	-1.482133E-01
1.1800E+00	-1.238939E-01	-9.761279E-02	-1.497254E-01
1.2000E+00	-1.251833E-01	-9.860433E-02	-1.512039E-01

1.3000E+00 -1.311260E-01 -1.031452E-01 -1.585975E-01

1.3200E+00 -1.321868E-01 -1.039972E-01 -1.600096E-01

1.3400E+00 -1.332201E-01 -1.048306E-01 -1.614011E-01

1.4400E+00 -1.383723E-01 -1.086277E-01 -1.679203E-01

1.5200E+00 -1.420538E-01 -1.113135E-01 -1.725039E-01

1.5400E+00 -1.429295E-01 -1.119399E-01 -1.735743E-01

1.5600E+00 -1.437683E-01 -1.125581E-01 -1.746176E-01

1.7200E+00 -1.497146E-01 -1.170418E-01 -1.821637E-01

1.7800E+00 -1.515985E-01 -1.185236E-01 -1.846390E-01

1.8600E+00 -1.538854E-01 -1.203832E-01 -1.876587E-01

1.9600E+00 -1.565615E-01 -1.229360E-01 -1.909989E-01

2.0400E+00 -1.586352E-01 -1.255165E-01 -1.934259E-01

2.1800E+00 -1.622955E-01 -1.299080E-01 -1.969026E-01

2.4400E+00 -1.696881E-01 -1.380636E-01 -2.029959E-01

6.6000E+00 -2.877126E-01 -2.685534E-01 -3.125348E-0

[Pulldown]

-3.3000E+00 -6.810660E-01 -5.230670E-01 -8.424876E-01

-9.6000E-01 -1.981282E-01 -1.521649E-01 -2.450873E-01

-9.4000E-01 -1.940006E-01 -1.489948E-01 -2.399813E-01

-9.0000E-01 -1.857452E-01 -1.426546E-01 -2.297693E-01

-8.8000E-01 -1.816176E-01 -1.394845E-01 -2.246633E-01

-8.6000E-01 -1.774899E-01 -1.363144E-01 -2.195574E-01

-8.4000E-01 -1.733622E-01 -1.331443E-01 -2.144514E-01

-8.2000E-01 -1.692345E-01 -1.299742E-01 -2.093454E-01

-8.0000E-01 -1.651069E-01 -1.268041E-01 -2.042394E-01

-7.8000E-01 -1.609792E-01 -1.236340E-01 -1.991334E-01

-7.6000E-01 -1.568515E-01 -1.204639E-01 -1.940274E-01

-7.4000E-01 -1.527239E-01 -1.172938E-01 -1.889215E-01

-7.2000E-01 -1.485962E-01 -1.141237E-01 -1.839359E-01

-7.0000E-01 -1.444685E-01 -1.109536E-01 -1.790393E-01

-6.8000E-01 -1.403408E-01 -1.077835E-01 -1.742835E-01

-6.6000E-01 -1.362132E-01 -1.046134E-01 -1.696438E-01

-6.2000E-01 -1.279578E-01 -9.827318E-02 -1.601522E-01

-5.8000E-01 -1.197025E-01 -9.193297E-02 -1.501460E-01

-5.6000E-01 -1.155748E-01 -8.876287E-02 -1.450729E-01

-5.4000E-01 -1.114471E-01 -8.559277E-02 -1.399880E-01

-5.0000E-01 -1.031918E-01 -7.925256E-02 -1.297599E-01

-2.6000E-01 -5.365973E-02 -4.121133E-02 -6.673053E-02

-4.0000E-02 -8.255344E-03 -6.340205E-03 -1.030969E-02

-2.0000E-02 -4.188663E-03 -3.224136E-03 -5.223194E-03

4.0000E-02 7.827601E-03 5.952943E-03 9.846129E-03

8.0000E-02 1.567453E-02 1.190207E-02 1.971115E-02

1.4000E-01 2.716085E-02 2.058063E-02 3.417789E-02

1.6000E-01 3.083472E-02 2.338738E-02 3.883737E-02

2.0000E-01 3.777044E-02 2.866909E-02 4.763949E-02

2.8000E-01 5.135191E-02 3.881227E-02 6.478476E-02

3.2000E-01	5.799397E-02	4.379972E-02	7.317325E-02
3.4000E-01	6.121792E-02	4.622375E-02	7.726210E-02
3.6000E-01	6.438343E-02	4.859826E-02	8.127453E-02
4.2000E-01	7.358994E-02	5.548982E-02	9.290387E-02
4.4000E-01	7.653245E-02	5.766834E-02	9.660568E-02
5.0000E-01	8.493634E-02	6.395376E-02	1.072471E-01
5.2000E-01	8.760295E-02	6.595997E-02	1.106363E-01
5.6000E-01	9.276238E-02	6.986360E-02	1.171992E-01
5.8000E-01	9.525975E-02	7.174434E-02	1.203566E-01
6.0000E-01	9.767248E-02	7.353576E-02	1.233948E-01
6.2000E-01	9.996119E-02	7.521600E-02	1.262696E-01
6.8000E-01	1.063191E-01	7.992019E-02	1.342615E-01
7.0000E-01	1.084050E-01	8.146118E-02	1.368534E-01
7.2000E-01	1.104446E-01	8.296981E-02	1.393938E-01
7.8000E-01	1.161924E-01	8.722829E-02	1.466606E-01
8.4000E-01	1.214638E-01	9.108450E-02	1.532526E-01
8.6000E-01	1.230850E-01	9.227444E-02	1.552834E-01
9.4000E-01	1.289832E-01	9.660581E-02	1.627444E-01
9.8000E-01	1.316287E-01	9.852567E-02	1.660777E-01
1.0200E+00	1.340100E-01	1.002640E-01	1.691123E-01
1.0400E+00	1.351185E-01	1.010736E-01	1.705297E-01
1.1000E+00	1.380611E-01	1.031943E-01	1.742858E-01
1.1200E+00	1.389582E-01	1.038366E-01	1.754290E-01

1.2000E+00 1.421600E-01 1.060597E-01 1.796446E-01

1.2200E+00 1.428843E-01 1.065412E-01 1.805838E-01

1.2800E+00 1.448135E-01 1.078531E-01 1.831174E-01

1.3600E+00 1.468975E-01 1.093701E-01 1.858346E-01

1.3800E+00 1.473382E-01 1.097002E-01 1.864128E-01

1.4600E+00 1.488132E-01 1.107563E-01 1.883651E-01

1.4800E+00 1.491090E-01 1.109612E-01 1.887700E-01

1.6200E+00 1.507036E-01 1.120590E-01 1.908964E-01

1.7200E+00 1.514269E-01 1.126503E-01 1.918469E-01

1.9200E+00 1.523521E-01 1.134931E-01 1.927091E-01

1.9400E+00 1.523912E-01 1.135583E-01 1.927644E-01

2.0200E+00 1.525379E-01 1.137760E-01 1.929123E-01

6.6000E+00 1.578610E-01 1.219851E-01 1.929411E-01

[Rising Waveform]

R_fixture = 50.000

V_fixture = 0.000

V_fixture_min = 0.000

V_fixture_max = 0.000

| time V(typ) V(min) V(max)

0.000S 831.892uV 954.660uV -8.645mV

100.000pS -6.371mV -5.953mV -24.833mV

110.000pS -7.612mV -7.044mV -26.363mV

200.000pS -21.202mV -18.694mV -41.118mV

260.000pS	-29.996mV	-23.377mV	-52.020mV
310.000pS	-39.046mV	-27.183mV	-62.971mV
420.000pS	-56.708mV	-41.447mV	-88.078mV
440.000pS	-60.027mV	-43.078mV	-91.255mV
480.000pS	-65.117mV	-44.966mV	-97.446mV
490.000pS	-66.308mV	-45.254mV	-99.129mV
510.000pS	-68.934mV	-45.727mV	-102.553mV
570.000pS	-78.058mV	-47.006mV	-108.051mV
580.000pS	-79.312mV	-47.154mV	-107.565mV
610.000pS	-81.812mV	-47.337mV	-104.006mV
630.000pS	-82.041mV	-47.233mV	-100.221mV
640.000pS	-81.615mV	-47.128mV	-97.794mV
690.000pS	-75.221mV	-46.245mV	-79.198mV
700.000pS	-73.441mV	-45.892mV	-74.194mV
710.000pS	-71.475mV	-45.350mV	-68.803mV
740.000pS	-64.073mV	-41.910mV	-50.148mV
760.000pS	-57.850mV	-38.183mV	-35.584mV
770.000pS	-54.327mV	-36.112mV	-27.708mV
800.000pS	-41.926mV	-29.275mV	-1.991mV
840.000pS	-21.614mV	-17.709mV	36.265mV
910.000pS	23.117mV	8.625mV	112.238mV
1000.000pS	93.514mV	51.607mV	223.152mV
1.040nS	128.123mV	73.610mV	276.358mV

1.050nS	137.036mV	79.418mV	289.984mV
1.140nS	221.327mV	136.216mV	415.233mV
1.310nS	393.190mV	250.762mV	655.557mV
1.440nS	534.221mV	344.573mV	843.384mV
1.690nS	805.950mV	532.363mV	1.206V
1.820nS	946.012mV	631.054mV	1.386V
1.890nS	1.023V	684.262mV	1.482V
2.170nS	1.321V	895.167mV	1.864V
2.220nS	1.374V	932.939mV	1.937V
2.280nS	1.435V	978.923mV	2.024V
2.390nS	1.549V	1.066V	2.167V
2.440nS	1.600V	1.104V	2.229V
2.640nS	1.803V	1.256V	2.452V
2.770nS	1.927V	1.352V	2.573V
2.870nS	2.021V	1.425V	2.651V
3.020nS	2.152V	1.533V	2.750V
3.130nS	2.239V	1.610V	2.812V
3.150nS	2.254V	1.624V	2.822V
3.240nS	2.316V	1.684V	2.865V
3.250nS	2.323V	1.691V	2.870V
3.330nS	2.374V	1.746V	2.904V
3.350nS	2.386V	1.759V	2.912V
3.580nS	2.503V	1.903V	2.991V

3.590nS	2.508V	1.909V	2.994V
3.610nS	2.517V	1.921V	3.000V
3.670nS	2.542V	1.955V	3.017V
3.830nS	2.602V	2.040V	3.060V
3.920nS	2.632V	2.083V	3.080V
4.000nS	2.657V	2.121V	3.095V
4.090nS	2.682V	2.163V	3.110V
4.120nS	2.689V	2.175V	3.114V
4.200nS	2.709V	2.206V	3.128V
4.230nS	2.715V	2.216V	3.131V
4.390nS	2.748V	2.265V	3.150V
4.440nS	2.757V	2.280V	3.153V
4.500nS	2.767V	2.298V	3.156V
4.510nS	2.769V	2.300V	3.157V
4.670nS	2.793V	2.339V	3.172V
4.700nS	2.797V	2.346V	3.173V
4.780nS	2.807V	2.362V	3.174V
4.800nS	2.810V	2.367V	3.174V
4.850nS	2.816V	2.376V	3.175V
4.870nS	2.818V	2.380V	3.175V
4.930nS	2.820V	2.392V	3.175V
4.980nS	2.823V	2.399V	3.175V
4.990nS	2.824V	2.401V	3.175V

5.150nS	2.839V	2.424V	3.177V
5.210nS	2.841V	2.435V	3.177V
5.220nS	2.841V	2.436V	3.177V
5.330nS	2.842V	2.449V	3.177V
5.360nS	2.843V	2.454V	3.177V
5.390nS	2.844V	2.458V	3.178V
5.460nS	2.848V	2.464V	3.178V
5.540nS	2.853V	2.474V	3.177V
5.580nS	2.855V	2.479V	3.177V
5.590nS	2.855V	2.480V	3.178V
5.610nS	2.856V	2.481V	3.178V
5.630nS	2.857V	2.483V	3.178V
5.660nS	2.858V	2.484V	3.178V
5.690nS	2.859V	2.485V	3.178V
5.760nS	2.860V	2.488V	3.178V
5.770nS	2.861V	2.489V	3.178V
5.800nS	2.861V	2.492V	3.178V
5.880nS	2.862V	2.501V	3.180V
5.910nS	2.862V	2.503V	3.181V
5.980nS	2.862V	2.506V	3.183V
6.000nS	2.862V	2.507V	3.183V
6.020nS	2.862V	2.507V	3.184V
6.040nS	2.862V	2.508V	3.184V

6.050nS	2.862V	2.508V	3.184V
6.060nS	2.862V	2.508V	3.184V
6.100nS	2.862V	2.511V	3.184V
6.150nS	2.862V	2.513V	3.184V

[Falling Waveform]

R_fixture = 50.000

V_fixture = 0.000

V_fixture_min = 0.000

V_fixture_max = 0.000

time	V(typ)	V(min)	V(max)
0.000S	2.862V	2.513V	3.194V
50.000pS	2.866V	2.509V	3.199V
100.000pS	2.869V	2.506V	3.201V
110.000pS	2.870V	2.506V	3.201V
130.000pS	2.871V	2.504V	3.201V
140.000pS	2.871V	2.503V	3.201V
150.000pS	2.871V	2.501V	3.201V
180.000pS	2.872V	2.496V	3.201V
190.000pS	2.872V	2.494V	3.201V
200.000pS	2.871V	2.493V	3.201V
220.000pS	2.870V	2.489V	3.200V
230.000pS	2.870V	2.487V	3.199V
320.000pS	2.862V	2.467V	3.185V

360.000pS	2.859V	2.457V	3.179V
380.000pS	2.857V	2.452V	3.174V
400.000pS	2.853V	2.446V	3.170V
450.000pS	2.843V	2.429V	3.157V
470.000pS	2.839V	2.421V	3.150V
510.000pS	2.829V	2.405V	3.134V
540.000pS	2.821V	2.392V	3.120V
560.000pS	2.815V	2.382V	3.109V
640.000pS	2.786V	2.338V	3.054V
650.000pS	2.782V	2.332V	3.045V
660.000pS	2.777V	2.325V	3.037V
720.000pS	2.746V	2.281V	2.972V
730.000pS	2.740V	2.273V	2.960V
750.000pS	2.727V	2.256V	2.932V
760.000pS	2.721V	2.247V	2.918V
810.000pS	2.685V	2.201V	2.837V
830.000pS	2.668V	2.181V	2.801V
850.000pS	2.651V	2.160V	2.762V
910.000pS	2.590V	2.091V	2.634V
950.000pS	2.542V	2.041V	2.540V
970.000pS	2.515V	2.012V	2.491V
1.020nS	2.441V	1.937V	2.362V
1.060nS	2.377V	1.877V	2.255V

1.120nS	2.273V	1.786V	2.091V
1.140nS	2.236V	1.755V	2.036V
1.210nS	2.099V	1.645V	1.841V
1.350nS	1.800V	1.417V	1.463V
1.360nS	1.778V	1.401V	1.437V
1.500nS	1.480V	1.180V	1.096V
1.610nS	1.255V	1.016V	848.706mV
1.620nS	1.235V	1.002V	827.301mV
1.690nS	1.099V	903.739mV	685.679mV
1.730nS	1.026V	850.095mV	609.517mV
1.790nS	920.764mV	773.495mV	501.994mV
1.830nS	852.397mV	723.765mV	435.396mV
1.980nS	620.668mV	555.804mV	230.335mV
2.020nS	564.504mV	515.254mV	188.507mV
2.090nS	469.329mV	448.097mV	128.414mV
2.120nS	431.020mV	420.232mV	107.907mV
2.180nS	359.457mV	366.553mV	74.857mV
2.190nS	348.144mV	357.778mV	70.148mV
2.200nS	337.037mV	349.035mV	65.674mV
2.220nS	315.509mV	331.825mV	57.500mV
2.230nS	305.073mV	323.390mV	53.755mV
2.270nS	265.208mV	291.526mV	39.901mV
2.290nS	246.494mV	276.475mV	33.946mV

2.310nS	228.718mV	261.828mV	29.096mV
2.320nS	220.155mV	254.618mV	27.013mV
2.360nS	188.121mV	226.661mV	19.186mV
2.370nS	180.705mV	219.986mV	17.123mV
2.390nS	166.586mV	207.124mV	13.004mV
2.420nS	147.140mV	188.819mV	7.617mV
2.470nS	118.935mV	160.884mV	2.430mV
2.500nS	104.222mV	145.754mV	1.031mV
2.510nS	99.748mV	140.962mV	698.694uV
2.540nS	87.296mV	127.219mV	-120.097uV
2.560nS	79.616mV	118.568mV	-500.086uV
2.580nS	72.713mV	110.232mV	-764.547uV
2.610nS	63.409mV	98.813mV	-1.088mV
2.640nS	54.597mV	88.583mV	-1.506mV
2.660nS	49.454mV	82.045mV	-1.807mV
2.680nS	45.001mV	76.045mV	-2.019mV
2.700nS	40.791mV	70.672mV	-2.093mV
2.720nS	36.473mV	65.502mV	-2.005mV
2.760nS	28.244mV	55.231mV	-1.514mV
2.770nS	26.530mV	52.923mV	-1.367mV
2.810nS	21.734mV	44.615mV	-788.653uV
2.830nS	20.382mV	40.362mV	-546.497uV
2.840nS	19.868mV	38.191mV	-440.272uV

2.890nS	17.686mV	28.714mV	-87.890uV
2.900nS	17.183mV	27.389mV	-51.781uV
2.910nS	16.643mV	26.267mV	-22.374uV
2.920nS	16.071mV	25.339mV	3.132uV
2.930nS	15.474mV	24.564mV	25.337uV
3.010nS	9.764mV	19.216mV	199.877uV
3.040nS	7.738mV	16.004mV	253.490uV
3.070nS	6.034mV	12.116mV	309.503uV
3.090nS	5.110mV	9.532mV	415.928uV
3.100nS	4.679mV	8.319mV	503.548uV
3.110nS	4.260mV	7.192mV	605.772uV
3.150nS	2.733mV	3.810mV	896.340uV
3.160nS	2.451mV	3.260mV	908.243uV
3.170nS	2.226mV	2.810mV	903.241uV
3.200nS	1.832mV	1.921mV	847.328uV
3.240nS	1.462mV	1.350mV	778.412uV
3.280nS	1.001mV	1.045mV	745.505uV
3.300nS	831.892uV	954.660uV	737.903uV

[Rising Waveform]

R_fixture = 50.000

V_fixture = 3.300

V_fixture_min = 3.000

V_fixture_max = 3.600

time	V(typ)	V(min)	V(max)
0.000S	328.218mV	390.746mV	286.809mV
70.000pS	341.922mV	412.944mV	291.623mV
130.000pS	357.579mV	436.293mV	303.759mV
140.000pS	360.795mV	440.926mV	306.360mV
230.000pS	401.478mV	492.493mV	340.605mV
240.000pS	407.310mV	499.407mV	345.727mV
260.000pS	419.810mV	513.988mV	357.061mV
320.000pS	466.187mV	566.384mV	403.468mV
330.000pS	475.478mV	576.441mV	413.405mV
350.000pS	495.771mV	597.770mV	435.423mV
400.000pS	558.329mV	657.868mV	504.819mV
410.000pS	573.005mV	671.050mV	521.546mV
420.000pS	588.391mV	684.656mV	539.312mV
540.000pS	821.120mV	878.556mV	833.617mV
550.000pS	844.393mV	897.197mV	863.741mV
610.000pS	998.410mV	1.015V	1.058V
740.000pS	1.364V	1.292V	1.495V
840.000pS	1.629V	1.504V	1.796V
860.000pS	1.678V	1.544V	1.852V
870.000pS	1.703V	1.564V	1.879V
980.000pS	1.943V	1.765V	2.153V
1.030nS	2.039V	1.846V	2.264V

1.050nS	2.075V	1.877V	2.306V
1.060nS	2.093V	1.892V	2.327V
1.120nS	2.194V	1.979V	2.449V
1.150nS	2.243V	2.023V	2.507V
1.180nS	2.289V	2.064V	2.563V
1.190nS	2.305V	2.077V	2.581V
1.200nS	2.319V	2.090V	2.599V
1.210nS	2.334V	2.103V	2.617V
1.270nS	2.417V	2.171V	2.723V
1.320nS	2.482V	2.223V	2.807V
1.390nS	2.569V	2.289V	2.920V
1.400nS	2.581V	2.298V	2.936V
1.420nS	2.605V	2.315V	2.967V
1.560nS	2.761V	2.431V	3.170V
1.570nS	2.772V	2.438V	3.183V
1.590nS	2.793V	2.453V	3.210V
1.600nS	2.803V	2.461V	3.223V
1.680nS	2.883V	2.520V	3.318V
1.730nS	2.931V	2.555V	3.369V
1.750nS	2.949V	2.568V	3.388V
1.790nS	2.984V	2.595V	3.422V
1.820nS	3.010V	2.614V	3.446V
1.910nS	3.080V	2.671V	3.501V

1.920nS	3.087V	2.677V	3.506V
1.940nS	3.100V	2.688V	3.515V
2.010nS	3.142V	2.726V	3.543V
2.030nS	3.153V	2.737V	3.549V
2.040nS	3.158V	2.742V	3.552V
2.140nS	3.203V	2.791V	3.575V
2.150nS	3.206V	2.795V	3.576V
2.160nS	3.210V	2.800V	3.577V
2.300nS	3.248V	2.850V	3.593V
2.320nS	3.252V	2.856V	3.595V
2.350nS	3.256V	2.865V	3.597V
2.380nS	3.260V	2.873V	3.598V
2.410nS	3.264V	2.881V	3.599V
2.450nS	3.271V	2.891V	3.599V
2.460nS	3.272V	2.893V	3.599V
2.480nS	3.275V	2.898V	3.599V
2.510nS	3.277V	2.905V	3.599V
2.520nS	3.278V	2.907V	3.599V
2.540nS	3.279V	2.910V	3.600V
2.590nS	3.281V	2.916V	3.600V
2.600nS	3.282V	2.918V	3.600V
2.620nS	3.283V	2.921V	3.600V
2.630nS	3.284V	2.922V	3.600V

2.670nS	3.288V	2.929V	3.600V
2.690nS	3.291V	2.932V	3.600V
2.710nS	3.293V	2.934V	3.600V
2.720nS	3.294V	2.935V	3.600V
2.750nS	3.296V	2.939V	3.600V
2.760nS	3.297V	2.940V	3.600V
2.780nS	3.298V	2.943V	3.600V
2.800nS	3.299V	2.946V	3.600V
2.830nS	3.299V	2.951V	3.600V
2.850nS	3.300V	2.953V	3.600V
2.860nS	3.300V	2.954V	3.600V
2.870nS	3.300V	2.955V	3.600V
2.890nS	3.300V	2.956V	3.600V
2.900nS	3.300V	2.956V	3.600V
2.920nS	3.300V	2.957V	3.600V
2.930nS	3.300V	2.957V	3.600V
2.940nS	3.300V	2.958V	3.600V
2.950nS	3.300V	2.959V	3.600V
2.980nS	3.300V	2.961V	3.600V
2.990nS	3.300V	2.962V	3.600V
3.020nS	3.300V	2.966V	3.600V
3.050nS	3.300V	2.970V	3.600V
3.060nS	3.300V	2.971V	3.600V

3.080nS	3.300V	2.974V	3.600V
3.140nS	3.300V	2.978V	3.600V
3.200nS	3.300V	2.983V	3.600V
3.260nS	3.300V	2.991V	3.600V
3.310nS	3.300V	2.997V	3.600V
3.360nS	3.300V	2.999V	3.600V
3.370nS	3.300V	2.999V	3.600V
3.390nS	3.300V	3.000V	3.600V
3.430nS	3.300V	3.000V	3.600V

[Falling Waveform]

R_fixture = 50.000

V_fixture = 3.300

V_fixture_min = 3.000

V_fixture_max = 3.600

time	V(typ)	V(min)	V(max)
0.000S	3.300V	3.000V	3.600V
80.000pS	3.312V	3.010V	3.614V
220.000pS	3.331V	3.017V	3.640V
240.000pS	3.334V	3.018V	3.643V
250.000pS	3.336V	3.019V	3.645V
320.000pS	3.342V	3.027V	3.652V
390.000pS	3.349V	3.032V	3.662V
430.000pS	3.354V	3.033V	3.667V

480.000pS	3.359V	3.034V	3.671V
540.000pS	3.362V	3.034V	3.672V
550.000pS	3.362V	3.034V	3.672V
580.000pS	3.363V	3.034V	3.672V
600.000pS	3.364V	3.034V	3.672V
610.000pS	3.364V	3.034V	3.672V
650.000pS	3.365V	3.032V	3.670V
670.000pS	3.365V	3.031V	3.667V
690.000pS	3.365V	3.030V	3.664V
700.000pS	3.365V	3.029V	3.662V
740.000pS	3.365V	3.024V	3.654V
750.000pS	3.365V	3.023V	3.652V
770.000pS	3.364V	3.020V	3.647V
840.000pS	3.362V	3.014V	3.625V
870.000pS	3.359V	3.011V	3.614V
880.000pS	3.357V	3.009V	3.610V
980.000pS	3.340V	2.993V	3.558V
1.010nS	3.333V	2.987V	3.539V
1.070nS	3.317V	2.974V	3.494V
1.080nS	3.314V	2.972V	3.486V
1.130nS	3.299V	2.959V	3.442V
1.150nS	3.293V	2.954V	3.423V
1.260nS	3.247V	2.920V	3.307V

1.350nS	3.197V	2.887V	3.201V
1.420nS	3.152V	2.856V	3.118V
1.480nS	3.110V	2.828V	3.045V
1.550nS	3.056V	2.792V	2.959V
1.590nS	3.023V	2.771V	2.907V
1.810nS	2.833V	2.646V	2.624V
2.000nS	2.661V	2.531V	2.366V
2.040nS	2.624V	2.507V	2.309V
2.270nS	2.403V	2.363V	1.986V
2.300nS	2.373V	2.344V	1.945V
2.530nS	2.142V	2.189V	1.629V
2.830nS	1.823V	1.975V	1.251V
2.870nS	1.778V	1.946V	1.205V
3.050nS	1.594V	1.807V	1.007V
3.070nS	1.574V	1.792V	986.481mV
3.220nS	1.427V	1.685V	842.054mV
3.250nS	1.398V	1.664V	816.111mV
3.440nS	1.222V	1.529V	675.942mV
3.460nS	1.204V	1.515V	663.656mV
3.600nS	1.085V	1.421V	587.318mV
3.810nS	921.478mV	1.286V	506.668mV
3.820nS	914.064mV	1.280V	503.492mV
3.890nS	864.860mV	1.237V	482.588mV

3.900nS	858.094mV	1.231V	479.936mV
4.050nS	763.853mV	1.141V	442.637mV
4.280nS	648.898mV	1.012V	398.810mV
4.370nS	613.200mV	964.560mV	388.692mV
4.490nS	571.433mV	905.611mV	372.743mV
4.570nS	547.930mV	867.454mV	364.065mV
4.640nS	529.721mV	836.428mV	355.178mV
4.730nS	507.177mV	798.025mV	350.971mV
4.820nS	490.687mV	761.901mV	347.698mV
4.860nS	482.951mV	746.735mV	344.657mV
4.980nS	461.558mV	705.509mV	334.082mV
5.030nS	454.524mV	689.349mV	331.918mV
5.260nS	423.218mV	621.527mV	328.777mV
5.290nS	419.328mV	613.559mV	328.248mV
5.300nS	418.188mV	611.114mV	328.005mV
5.320nS	416.200mV	606.600mV	327.407mV
5.350nS	413.832mV	599.826mV	326.418mV
5.490nS	399.892mV	568.041mV	321.414mV
5.540nS	395.276mV	560.090mV	319.390mV
5.670nS	388.185mV	536.290mV	315.505mV
5.770nS	379.848mV	518.573mV	312.495mV
5.840nS	374.470mV	506.231mV	311.544mV
5.860nS	373.341mV	502.733mV	311.252mV

5.930nS	370.393mV	494.427mV	310.517mV
6.010nS	367.333mV	481.398mV	310.176mV
6.030nS	366.140mV	478.852mV	310.076mV
6.090nS	362.453mV	473.798mV	309.819mV
6.180nS	355.614mV	460.993mV	309.423mV
6.200nS	354.314mV	458.451mV	309.299mV
6.220nS	353.185mV	456.524mV	309.154mV
6.250nS	351.864mV	454.564mV	308.946mV
6.280nS	350.956mV	453.057mV	308.586mV
6.310nS	350.291mV	450.914mV	308.022mV
6.330nS	349.955mV	448.811mV	307.584mV
6.420nS	348.323mV	436.909mV	304.631mV
6.500nS	346.250mV	431.696mV	301.189mV
6.530nS	344.949mV	429.270mV	299.588mV
6.650nS	337.905mV	414.910mV	293.750mV
6.710nS	334.693mV	411.977mV	291.381mV
6.780nS	331.943mV	409.690mV	289.968mV
6.790nS	331.577mV	409.142mV	289.837mV
6.800nS	331.239mV	408.490mV	289.719mV
6.870nS	329.789mV	400.844mV	289.078mV
6.930nS	329.135mV	394.638mV	288.555mV
6.960nS	328.905mV	392.666mV	288.194mV
7.020nS	328.218mV	390.746mV	286.809mV

[Ramp]

dV/dt_r 1.7179E+00/1.7258E-09 1.5076E+00/2.1211E-09 1.9156E+00/1.4464E-09

dV/dt_f 1.7831E+00/1.8567E-09 1.5656E+00/2.3885E-09 1.9879E+00/1.5398E-09

R_load = 50

[End]