Plan 9 is offering a Power Line Communications (PLC) Narrow Band (9-500kHz) Transmitter Intellectual Property (IP) line driver block designed to drive the low impedance loads with outstanding linearity and MTPR (Multi-Tone Power Ratio) performance driving OFDM signals.

***Applications include:***

- *All PLC related standards*
- *Smart power meter communications*
- *Smart House controls*

***Features of this IP Transmitter:***

- *3 Amp output @ VDD-2V*
- *>500KHz Full Power Bandwidth*
- *Fully Differential Input and Single ended Output*
- *Switchable hi-impedance output mode*
- *Fixed Gain of 8V/V*
- *<50mA idle current*
- *VDD range is 10V to 24V*
- *Programmable Short circuit Protection*
- *HiZ output holding circuit*
- *IP line driver total area is less than 1.25mm2*

***Description***

The AC power line was not designed for data transmission. High voltage, current spikes, induced noise, switching noise, low impedance loads, lossy transmission, etc., all challenge a communication channel and the frontline AFE components but especially the line driver. The Plan 9 line-driver is designed with some of these challenges in mind.

The line driver can drive low resistive loads at high current and still maintain the low distortion needed for OFDM signals.

The short circuit current limit is designed to clip the fast-moving signal (up to 500KHz). This allows for the signal timing and crossings to preserved during a clip. There are four choices of short circuit current.

During the output HiZ mode, the midpoint can sometimes drift from the active midpoint causing some transients during re-activation of the line driver. A mid-point hold circuit is used to keep the voltage during HiZ mode but not lower the open impedance at working frequencies.

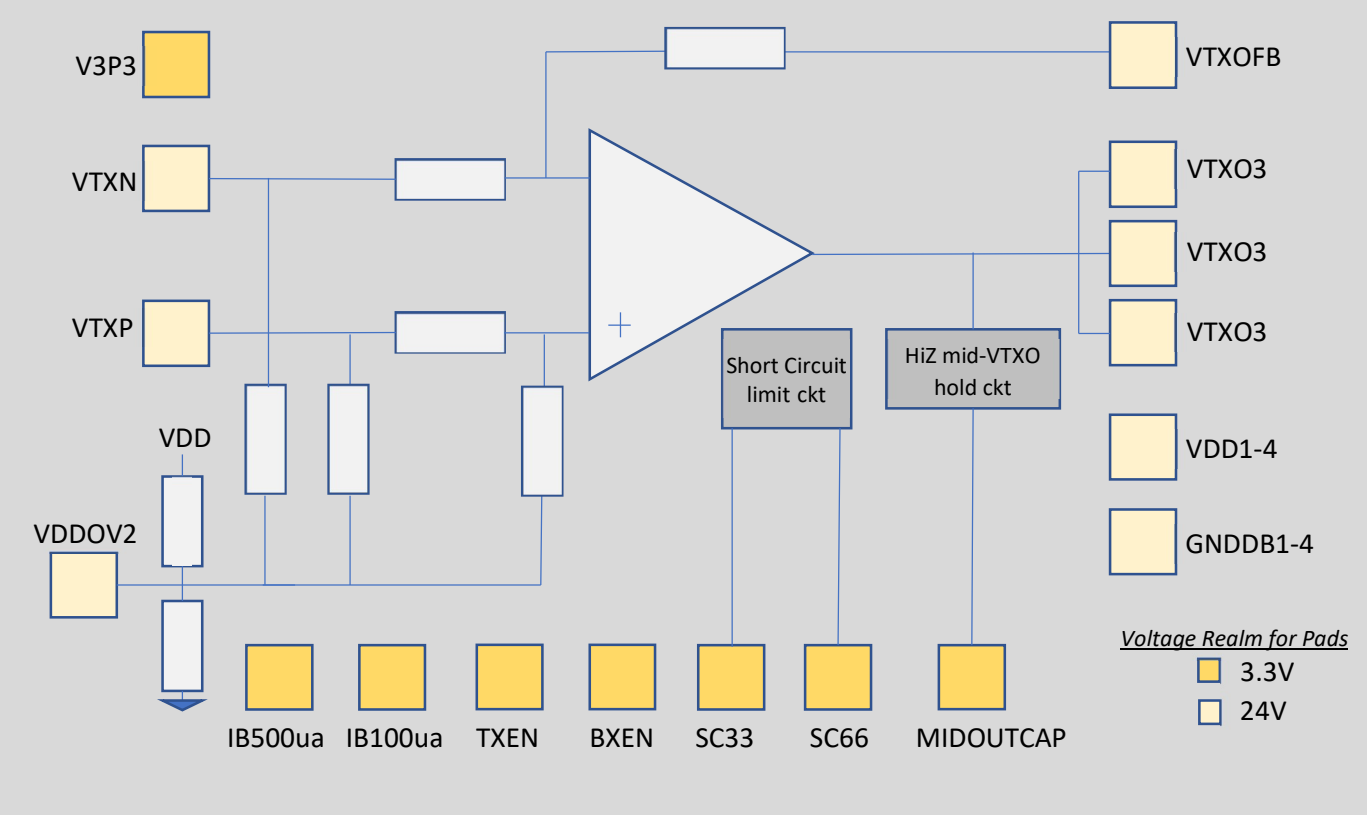
The input is fully differential to allow easy connection to fully differential TX PGA's and filters. Additional resistors are placed on the inputs to add further stability to hold the input voltages steady.

***Availability***

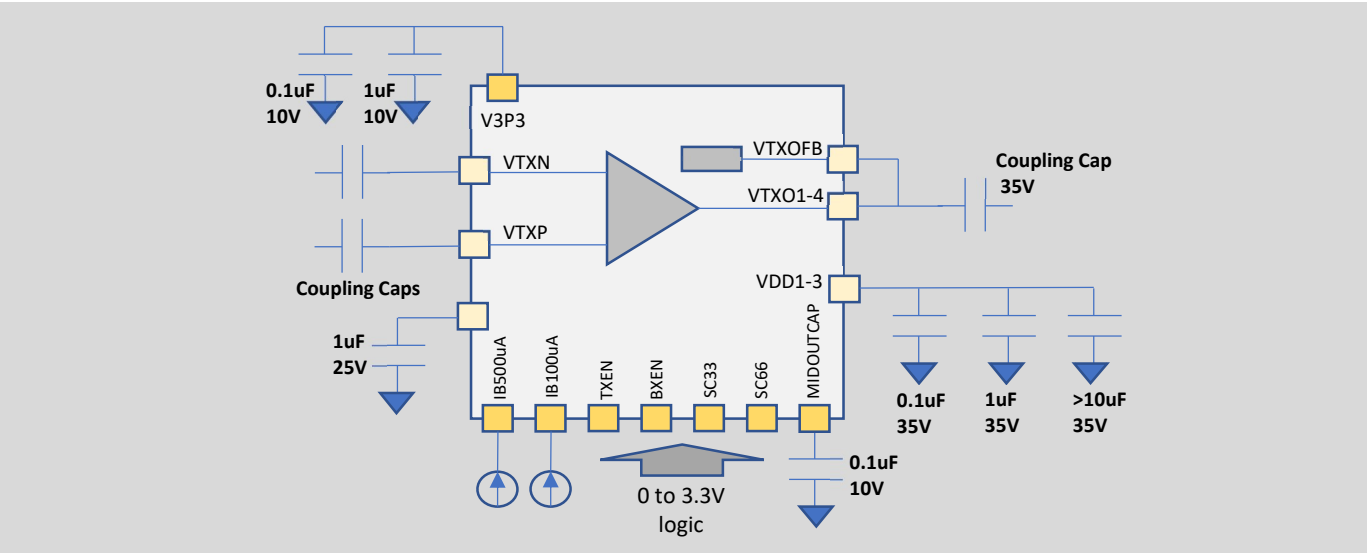
Additional information and demos are available with restrictions. Email: info@plan9inc.com

The IP ownership is offered for sale.

## Block Diagram




## Application Circuit



## Pin Description

| Pin Name | Pin on Package | ESD Requirements | Description |
|---|---|---|---|
| **MIDOUTCAP** | 3 | 5V | Filter for VOTX HiZ circuit, short to disable circuit |
| **SC33** | 4 | 5V | LSB Short circuit switch (see decoder) |
| **SC66** | 5 | 5V | MSB Short circuit switch (see decoder) |
| **VDDOV2** | 6 | 24V | Mid voltage reference cap |
| **VTXP** | 7 | 24V | Positive Input |
| **VTXN** | 8 | 24V | Negative Input |
| **VDD4** | 9 | 24V | VDD supply (in parallel) |
| **VDD3** | 10 | 24V | VDD supply (in parallel) |
| **VDD2** | 11 | 24V | VDD supply (in parallel) |
| **VDD1** | 12 | 24V | VDD supply (in parallel) |
| **VOTX3** | 13 | 24V | VOTX output pin (in parallel) |
| **VOTX2** | 14 | 24V | VOTX output pin (in parallel) |
| **VOTX1** | 15 | 24V | VOTX output pin (in parallel) |
| **VOTXFB** | 16 | 24V | VOTX resistor feedback pin (ties to VOTX) |
| **GNDDB1-4** | Paddle | none | Four down bond pads to paddle |
| **TXEN** | Internal | 5V | Active TX circuit from Standby, H-Active |
| **BXEN** | Internal | 5V | Activate Standby from Off, H-Active |
| **IB500ua** | Internal | 5V | Low Variation bias current 500uA |
| **IB100ua** | Internal | 5V | Low Variation Bias current 125uA |

## Specifications

Since this is an IP offering, the simulation results are included to show how well the silicon matches simulation. A large amount of agreement between the measured and simulated validates the simulations and that layout minimally impacts the design. Thus, with good agreement, simulations over the corners can be more relied upon to help predict the manufacturing performance limits.

Below are the Overall Conditions for testing, except where noted. The Transmitter was tested over 42 corners comprising of combinations of voltage, temperature, and process corner. In addition, Monte Carlo analysis was employed for certain tests.

Corners used are Typ., FF, SS, FS, SF with various combinations of resistor and capacitor corners.

VDD = 10V and 24V (tested at extreme range, see recommendations)
V3P3 = 3V and 3.6V
Junction Temperature = -40C, 27C, and 150C
Rload= 1 Ohm and 100 Ohms (resistive load)
Cload= 100pF

The actual measurements are in the "Measured" column next to the simulated. These are not exhaustive results over all temperatures but represent the type of performance to be expected.

***Absolute Max***

| Symbol | Description | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| | VDD | | -0.4 | | 24 | V |
| | V3P3 Supply Range | | -0.4 | | 5.5 | V |
| | Control pins- SC33, SC66, TXEN, BXEN | | -0.4 | | 5.5 | V |
| | VOTX | | -0.4 | | 24 | V |
| | Junction Temperature | | -40 | | 150 | C |

***Recommended***

| Symbol | Description | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| | VDD | | 10 | | 22 | V |
| | V3P3 Supply Range | | 3 | | 3.6 | V |
| | Junction Temperature | *depends on application | -40 | | 135* | C |

***Power Supply Voltages and Currents***

| | | | Spec/Sim | | | Measured | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Symbol** | **Description** | **Conditions** | **Min** | **Typ** | **Max** | **Min** | **Typ** | **Max** | **Units** |
| | VDD Supply Range | Measured at max VDD | 10 | | 24 | 10 | | 24, 20 | V |
| | V3P3 Supply Range | | 3 | | 3.6 | 3 | | 3.6 | V |
| | VDD Active Current | No signal (with Plan 9 bias) | 45 | | 48 | | 48-50 | | mA |
| | VDD Powered Down Current | VDD=24V | 240 | | 400 | | 230 | | uA |
| | VDD Powered Down Current | VDD=10V | | | | | 140 | | uA |
| | V3P3 Active Current | | 18 | | 28 | | | | uA |
| | V3P3 Powered Down Current | | 18 | | 28 | | | | uA |

***Transmitter Inputs***

| | | | Spec/Sim | | | Measured | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Symbol** | **Description** | **Conditions** | **Min** | **Typ** | **Max** | **Min** | **Typ** | **Max** | **Units** |
| | Input Nominal | | | VDD/2 | | | VDD/2 | | V |
| | Input Range (single ended) | | 0.875* VDD/2 | | 1.125* VDD/2 | | | | V |
| | Input offset Voltage Variation | Input referred | -2.5 | | 2.5 | -1 | | 1 | mV |
| | Input Impedance(each) | | 3.4 | 4.2 | 5.1 | | | | kOhm |

***Transmitter Output***

| | | | Spec/Sim | | | Measured | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Symbol** | **Description** | **Conditions** | **Min** | **Typ** | **Max** | **Min** | **Typ** | **Max** | **Units** |
| | Active Output Nominal | | | VDD/2 | | | VDD/2 | | V |
| | Output Range | Iout=3A | 2 | | VDD-2 | | 2 to VDD-2 | | V |
| | Peak Output Current | SC66=H, SC33=H, Allowable time duration at peak is TBD | 3 | | | | 3 | | A |
| | Active Output Voltage | VDD=24V<br>VDD=15V<br>VDD=10V | 12.00002 | | 12.00013 | <br>7.497<br>4.995 | | <br>7.511<br>5.011 | V<br>V<br>V |
| | Active Output Impedance | At 250kHz<br>*estimated from gain change | | <50 | | | 8* | | mOhm |
| | HiZ Output Resistance | | 34 | | 51 | | | | kOhm |
| | HiZ Output Capacitance | | 61 | | 108 | | | | pF |
| | HiZ Voltage range | | 0 | | VDD | 0 | | VDD | V |
| | HiZ nominal Out Voltage | | | VDD/2 | | | | | V |
| | HiZ nominal Out Voltage | VDD=24V<br>VDD=15V<br>VDD=10V | 11.83 | | 12.02 | <br>7.370<br>4.740 | | <br>7.615<br>5.187 | V<br>V<br>V |
| | Pside SC Current Limit | SC66=H, SC33=H | | 3.1 | | | 3.2 | | A |
| | Pside SC Current Limit | SC66=H, SC33=L | | 2.7 | | | 2.7 | | A |
| | Pside SC Current Limit | SC66=L, SC33=H | | 2.1 | | | 2.4 | | A |
| | Pside SC Current Limit | SC66=L, SC33=L | | 1.7 | | | 1.9 | | A |
| | Nside SC Current Limit | SC66=H, SC33=H | | 3.2 | | | 3.3 | | A |
| | Nside SC Current Limit | SC66=H, SC33=L | | 2.8 | | | 3 | | A |
| | Nside SC Current Limit | SC66=L, SC33=H | | 2.2 | | | 2.4 | | A |
| | Nside SC Current Limit | SC66=L, SC33=L | | 1.7 | | | 1.8 | | A |

***Transmitter Bandwidth, Stability, Slew Rate***

| | | | Spec/Sim | | | Measured | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Symbol** | **Description** | **Conditions** | **Min** | **Typ** | **Max** | **Min** | **Typ** | **Max** | **Units** |
| | Gain | 100 Ohm load | 18.01 | | 18.06 | | 17.97 | | dB |
| | Gain | 1 Ohm load | 18.04 | | 18.08 | | 17.9 | | dB |
| | 3dB Bandwidth | 100 Ohm load | 2.26 | | 5.58 | | 3 | | MHz |
| | 3dB Bandwidth | 10 Ohm load | | | | | 3 | | MHz |
| | 3dB Bandwidth | 1 Ohm load | 3.29 | | 7.66 | | 2.7 | | MHz |
| | Peaking | 100 Ohm load | 0 | | 0.044 | | 0 | | dB |
| | Peaking | 1 Ohm load | 0 | | 2 | | 0 | | dB |
| | Small Signal Pulse Overshoot | 100 Ohm load, VTXO=40mVp | 0 | | 0.5 | | 1.6 | | % |
| | Small Signal Pulse Overshoot | 1 Ohm load, VTXO=40mVp | 0 | | 18.7 | | 1.4 | | % |
| | Slew Rate Plus | 100 Ohm load, 12Vpp (sim'd at 16Vpp), VDD=20V | 91.1 | | 161.8 | | 118 | | V/us |
| | Slew Rate Negative | same | -159.1 | | -90.2 | | -118 | | V/us |
| | Full Power Bandwidth | 100 Ohm load, 12Vpp, VDD=20V | 2.4 | | 4.2 | | 3.1 | | MHz |

***Transmitter Noise***

| | | | Spec/Sim | | | Measured | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Symbol** | **Description** | **Conditions** | **Min** | **Typ** | **Max** | **Min** | **Typ** | **Max** | **Units** |
| | Noise Density (input ref) | At 50KHz<br>At 250kHz | 16 | | 24.4 | | -<br>17 | | nV/rtHz<br>nV/rtHz |
| | CEN-A (output ref) | 35kHz to 95kHz | 31 | | 47 | | 35 | | uVrms |
| | CEN-B (output ref) | 95k to 125kHz | 20 | | 30 | | 25 | | uVrms |
| | CEN-C (output ref) | 125kHz to 140kHz | 14 | | 21 | | 18 | | uVrms |
| | CEN-D (output ref) | 140kHz to 148kHz | 10 | | 15.5 | | 13 | | uVrms |
| | ARIB Std-T84 (output ref) | 35kHz to 420kHz | 68 | | 104 | | 87 | | uVrms |
| | FCC-low (output ref) | 35kHz to 125kHz | 38 | | 56 | | 43 | | uVrms |
| | FCC-G3 (output ref) | 150kHz to 490kHz | 60 | | 94 | | 81 | | uVrms |
| | PSRR (VDD) Input Ref | 100 Ohm load, @50kHz | | | -102 | | | | dB |
| | PSRR (VDD) Input Ref | 1 Ohm load, @50kHz | | | -102 | | | | dB |

***Transmitter Distortion***

| | | | Spec/Sim | | | Measured | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Symbol** | **Description** | **Conditions** | **Min** | **Typ** | **Max** | **Min** | **Typ** | **Max** | **Units** |
| | 2nd Harmonic | 100 Ohm load, Vout=3Vp, Fund Freq=500kHz | -89 | | -84 | | -83 | | dB |
| | 2nd Harmonic | 10 Ohm load, same | | | | | -70 | | dB |
| | 2nd Harmonic | 1 Ohm load, same | -100 | | -64 | | -53 | | dB |
| | 3rd Harmonic | 100 Ohm load, same | -100 | | -80 | | -88 | | dB |
| | 3rd Harmonic | 10 Ohm load, same | | | | | -69 | | dB |
| | 3rd Harmonic | 1 Ohm load, same | -77 | | -54 | | -55 | | dB |
| | MTPR Average Bin | 100 Ohm load, 3Vp, CF=4, 260 tones (appx 9k to 480kHz) Fund freq=488.28125Hz | 72 | | 83 | | 90 | | dB |
| | MTPR Average Bin | 10 Ohm load, same as above | | | | | 90 | | dB |
| | MTPR Average Bin | 1 Ohm load, same as above | 51 | | 65 | | 71 | | dB |
| | MTPR Peak Bin | 100 Ohm load, same as above | 54 | | 71 | | 77 | | dB |
| | MTPR Peak Bin | 10 Ohm load, same as above | | | | | 75 | | dB |
| | MTPR Peak Bin | 1 Ohm load, same as above | 40 | | 57 | | 58 | | dB |

***Die Area***

Transmitter size, without bond pads and ESD, is 1400x890um = 1.246mm2

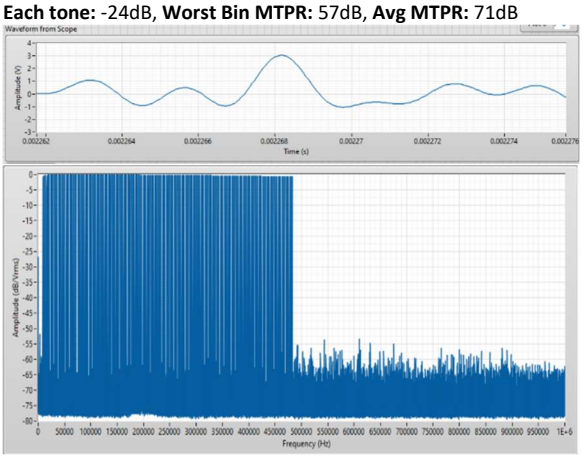
# Measurement Results

## MTPR

Typical Measurement result of MTPR signal with 260 tones producing peaks of 3V while driving a 1 Ohm load with VDD= 10V, is shown below. The peak current is 3A with the average current about 300mA. This measurement uses tones and empty bins evenly spaced. Intermodulation distortion collects in the empty bins and is compared to the signal, with both an average MTPR S/N and a worst-case bin calculation. All dB calculations are in Volts.

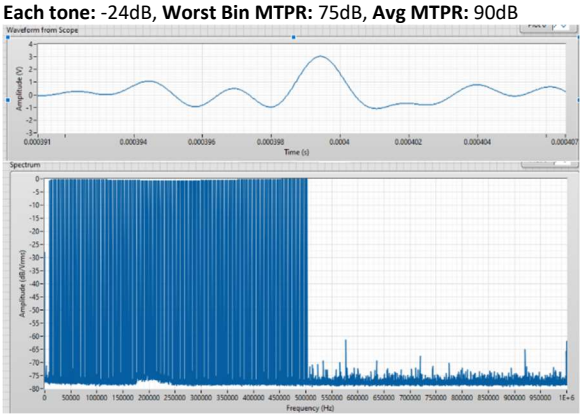
### *Load=1 Ω, VDD=10V or VDD=15V*

**Each tone:** -24dB, **Worst Bin MTPR:** 57dB, **Avg MTPR:** 71dB



### *Load=10 Ω*

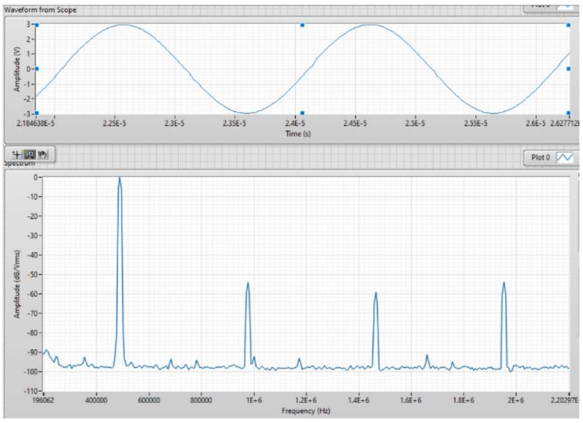
**Each tone:** -24dB, **Worst Bin MTPR:** 75dB, **Avg MTPR:** 90dB



## Harmonic Distortion

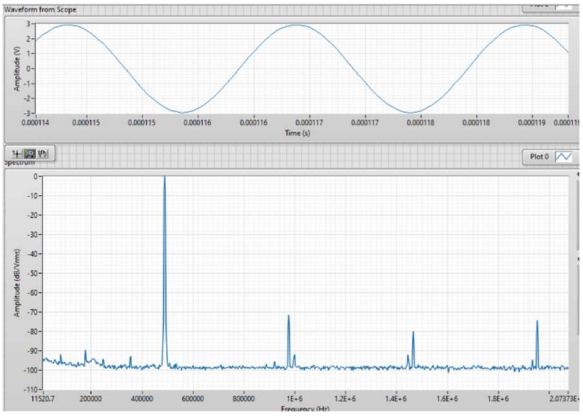
### *Vout = 6Vpp, Load= 1 Ω, VDD=10V or 15V*

2nd Harmonic: -54dB 3rd Harmonic: -60 to -55dB



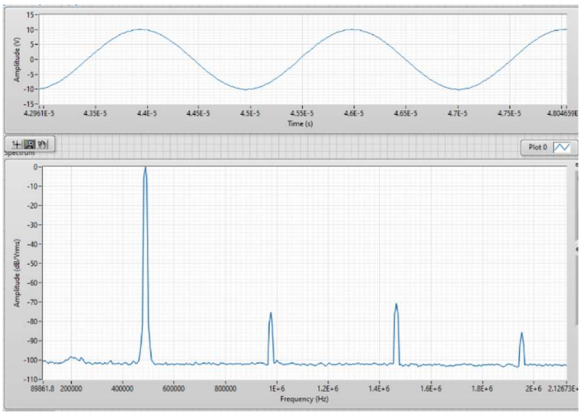
### *Vout = 6Vpp, Load= 10 Ω, VDD= 10 or 15V*

2nd Harmonic: -72dB 3rd Harmonic: -70 to -80dB



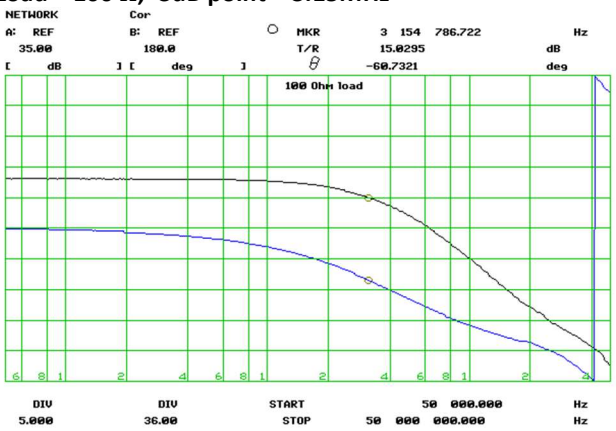
### *Vout = 20.5Vpp, Load= 50 Ω, VDD=21V*

2nd Harmonic: -75dB 3rd Harmonic: -71dB

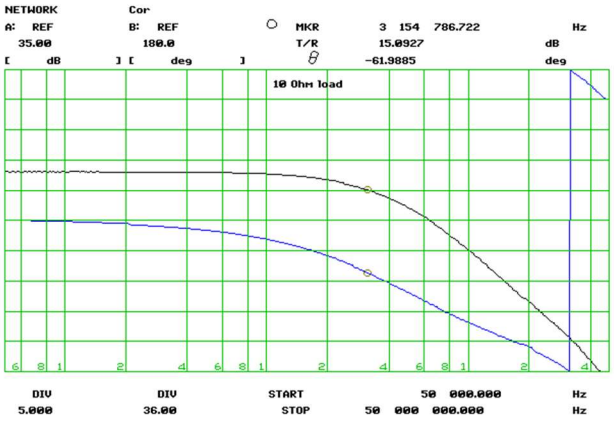


### *Bode Plot*

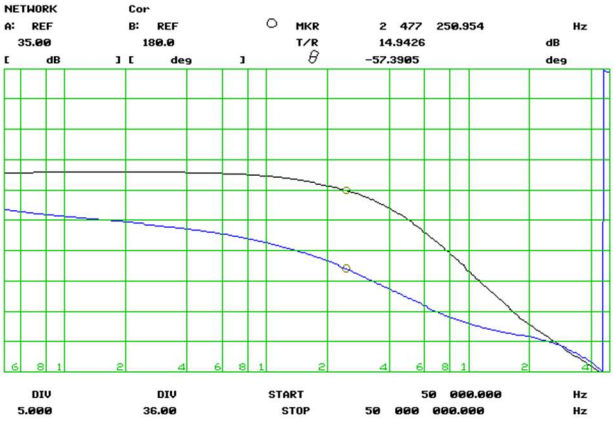
**Load = 100 Ω, -3dB point = 3.15MHz**




**Load = 10 Ω, -3dB point = 3.15MHz**

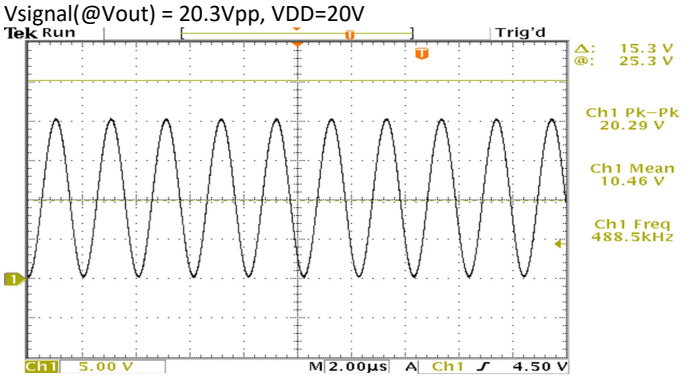



**Load = 1 Ω, -3dB point = 2.5MHz**



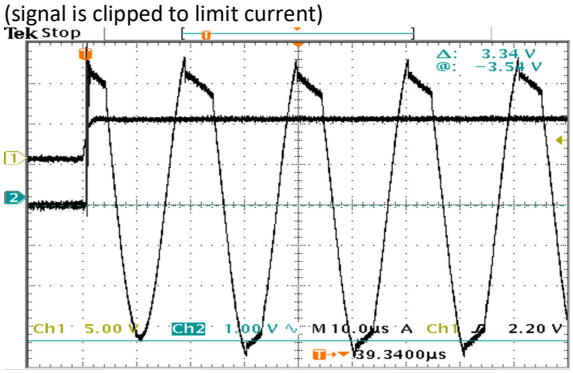

### *Signal driving Output during HiZ*

Vsignal(@Vout) = 20.3Vpp, VDD=20V



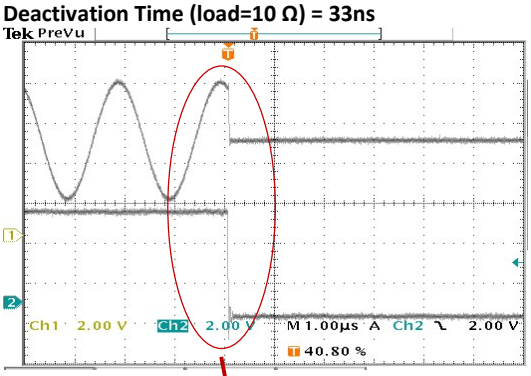

### *Short Circuit Protection 3.2A*

Set to 3.2A current limit VDD=10V
(signal is clipped to limit current)

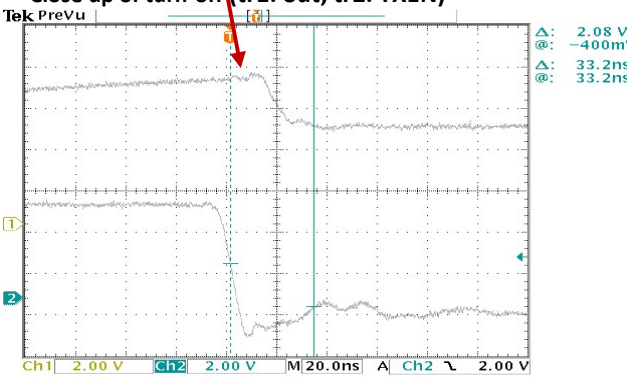


### *Output deactivating and going to HiZ mode*

**Deactivation Time (load=10 Ω) = 33ns**

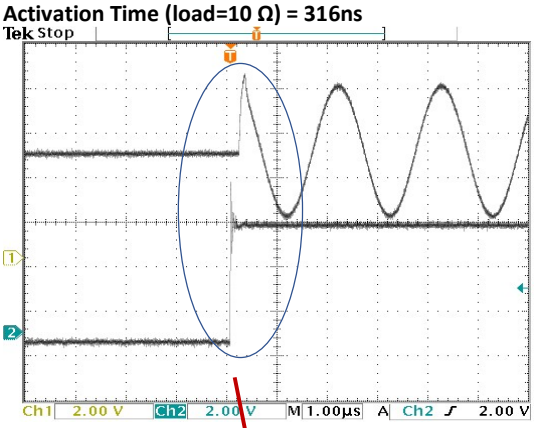



**Close up of turn-off (tr1: out, tr2: TXEN)**




### *Output activation and driving signal*

**Activation Time (load=10 Ω) = 316ns**




**Close up of turn-on (tr1: out, tr2: TXEN)**