

**RESULTS OF  
THE LABORATORY EVALUATION OF LINX ATSC PROTOTYPE  
RECEIVER WITH 8-VSB MODULATION FOR TERRESTRIAL  
BROADCASTING**

**FINAL REPORT**

**(Version 1.4)**

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**For  
LINX ELECTRONICS INC.**

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## **EXECUTIVE SUMMARY**

The Communications Research Centre Canada (CRC) carried out laboratory tests to evaluate the performance of a prototype ATSC receiver for terrestrial DTV broadcasting for LINX Electronics Inc.

The main results from the laboratory tests are summarized below:

1. The LINX receiver has a strong multipath capability. It can demodulate the signal under Brazil C, D and E multipath profiles.
2. The LINX receiver has much improved robustness against the pre-echo. It can withstand:
  - A -10 dB single echo within a delay range between  $-29.5 \mu\text{s}$  to  $+38.5 \mu\text{s}$ .
  - A -3 dB single echo within a delay range between  $-9.0 \mu\text{s}$  to  $+38.5 \mu\text{s}$ .
  - A 0 dB single echo over a  $12 \mu\text{s}$  range (Since there are two equal amplitude signals, time reference can not be selected).
3. The LINX receiver has a strong carrier recovery capability. It can acquire the signal even when the 8-VSB pilot was totally nulled out.

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## **1 Introduction**

A prototype ATSC 8-VSB digital television receiver was developed by LINX Electronics Inc. This prototype was evaluated in the laboratory of the Communications Research Centre Canada (CRC) against random noise, burst noise and multipath impairments; and co-channel and adjacent channel interference. This report outlines the results of these laboratory evaluations. The tests were carried out in March 2002.

## **2 Description of the LINX ATSC prototype receiver**

The LINX receiver is a prototype receiver designed to handle the severe multipath conditions that can often be encountered in the field. The front end consists of a single conversion consumer grade tuner and 10-bit A/D. A robust synchronization circuit drives an NCO to lock the carrier frequency and an external VCXO for sampling. It is designed to operate under severe channel degradation, including possible nulling of the VSB pilot.

The equalizer has a unique configuration that enables proper equalization of strong ghosts while minimizing noise enhancement. The equalizer is also designed to have sufficient length and speed to handle the complex ensembles that exist in both indoor and outdoor environments. The receiver also has a phase tracker for correcting high frequency phase noise from the tuner, as well as the requisite trellis decoder, deinterleaver, and Reed-Solomon decoder for error correction. The system is implemented with an FPGA circuit board encased in a 19 inch rack mount.

### **3 Laboratory set-up**

The LINX receiver is tested against impairments and interference. The impairments are random noise and burst noise, as well as multipath distortion with and without noise injection. In the case of interference, the tests included single tone, adjacent and co-channel interference from NTSC.

The laboratory set-up for the evaluation of the LINX receiver is presented in Figure 1. The set-up is divided in three sections: Transmitter, Channel and Receiver.

#### **3.1 Transmitter**

The DTV signal is obtained from a Rohde & Schwarz SFQ modulator. The test sequence is the SFQ internal PRBS data generator (pn-23).

#### **3.2 Channel**

The RF NTSC signal, used as interference, is obtained from a Drake VM2550A modulator. The NTSC modulator is fed by a Tektronix 1910 video test signal generator and by a Tektronix AM700 audio generator.

A Micronetics NOD-5250 generator is used to generate the random noise. The generator is connected to the combiner along with the desired DTV signal. A controlled gated noise is used with the noise generator to generate the burst noise. An HP89440A vector analyzer is used to calibrate the RF system.

An HP11759C channel simulator is used to simulate multipath distortion.

#### **3.3 Receiver**

The output signal from the combiner is connected to the LINX receiver.

The output of the LINX receiver is connected to an HP 3784A Bit Error Rate (BER) meter. The BER is used as reference measurement to determine the Threshold of Visibility (TOV) level, which is defined as  $BER = 3E-6$ .

#### **3.4 Test conditions**

The tests are done on VHF channel 12 (204-210 MHz).

BER tests are conducted. The TOV level is defined as  $BER = 3E-6$ .

For the C/N measurement in the case of Multipath, the signal power refers to the main signal power. Echo power was not included.

Without noise injection the HP11759C channel simulator has a C/N of 42 dB.

Multipath profile details are listed in Appendix A. Echo phases are referenced to the center of the RF channel.

The tests are conducted with and without signal re-acquisition.

- In this report “With Signal Re-acquisition (w. re-acq.)” means:

Disconnect the RF signal and re-acquire the signal to find the TOV, where the receiver can re-acquire the signal with the maximum impairment or interference.

- In this report “Without Signal Re-acquisition (w/o. re-acq.)” means:

Find the TOV with the maximum impairment or interference without re-acquiring the signal.

An HP89440A vector signal analyzer is connected at the combiner output, to make the average power measurements of the DTV, NTSC and random noise signals.

The NTSC signal used for the power measurement is the RF carrier modulated by a composite video signal with a black level of 7.5 IRE units. The correction factor for the NTSC average power to the visual carrier peak power is +2.60 dB.

For the NTSC undesired signal, the aural carrier is adjusted to 20% (7 dB below) of the visual carrier peak power.

The NTSC video signal is Color Bars. The NTSC audio signal is a 400 Hz tone.

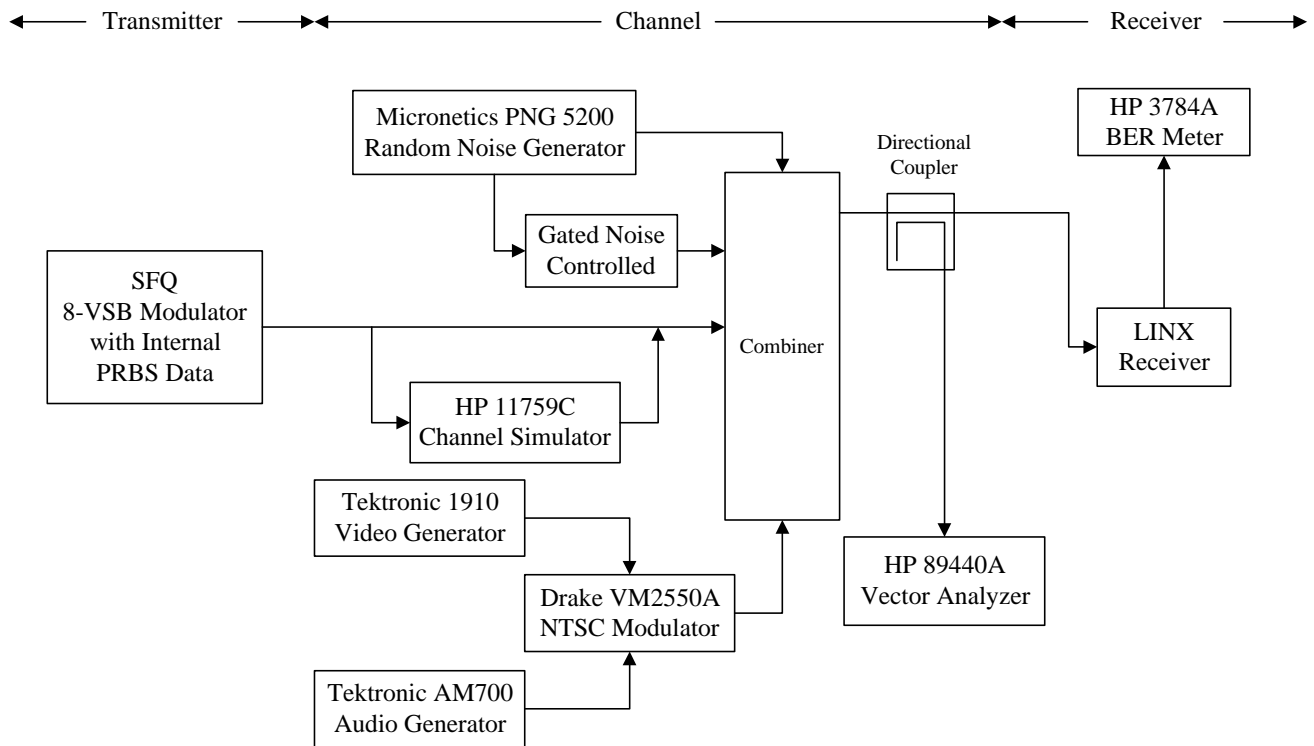


Figure 1. Set-up for Laboratory Evaluation of LINX Receiver

## 4 Test Procedures and results

The following procedures were intended to verify the performance of the LINX receiver. The tests included measurements on:

- Random noise
- Burst noise
- Multipath Ensembles
- Single Echo
- NTSC interference
- Phase noise

### 4.1 Susceptibility to Random Noise

The purpose of these tests is to determine the robustness of the LINX receiver to random noise impairment.

The DTV desired signal is adjusted at three different RF levels: Strong (-28 dBm), Moderate (-53 dBm) and Weak (-68 dBm). The noise level is increased until TOV is reached and the C/N value is recorded.

Signal Level	C/N (dB)	
	w/o. re-acq	w. re-acq
Strong	14.9	14.9
Moderate	15.1	15.1
Weak	15.1	15.1

Table 1. Susceptibility to Random Noise

### 4.2 Susceptibility to Burst Noise

The purpose of this test is to determine the robustness of the LINX receiver to gated random noise impairment.

The DTV desired signal is adjusted to Moderate level (-53 dBm). The gated noise level is 10 dB above random noise TOV (-58 dBm). The pulse width is increased until TOV is reached and the pulse width is measured and recorded.

Signal Level	C/N (dB)	Pulse Rate (Hz)	Pulse Width (ms)
Moderate	5	10	193.0

Table 2. Susceptibility to Burst Noise with Signal Re-acquisition

### 4.3 Susceptibility to Random Noise in the Presence of Static Multipath Ensembles

The purpose of the multipath testing is to determine how robust is the LINX receiver in the presence of static multipath ensembles with random noise injection.

The C/N at TOV is recorded for each multipath ensemble.

All the multipath tests are done with the desired DTV signal RF level adjusted to the Moderate level (−53 dBm).

Signal Level	Ensemble Type	C/N (dB)	
		w/o. re-acq	w. re-acq.
Moderate	Calibration	15.1	15.1
Moderate	Brazil A	15.3	15.3
Moderate	Brazil B	19.4	19.4
Moderate	Brazil C	12.5	12.5
Moderate	Brazil D	13.0	14.9
Moderate	Brazil E	22.8	24.8
Moderate	Special Brazil C	12.6	12.6

Table 3. Susceptibility to Random Noise in Presence of Static Multipath Ensembles

### 4.4 Susceptibility to Strongest Static Echoes

The purpose of the multipath testing is to determine how robust is the LINX receiver in the presence of a strong static echo in static multipath ensembles with and without random noise injection.

The echo power level at TOV is recorded for each multipath ensemble without noise injection.

If the receiver can handle a 0 dB echo without any errors, the C/N is recorded for TOV with noise injection.

All the multipath tests are done with the desired DTV signal RF level adjusted to the Moderate level (−53 dBm).

Signal Level	Ensemble Type	Echo Power (dB)	C/N (dB)	
			w/o. re-acq.	w. re-acq.
Moderate	Calibration	N/A	15	15
Moderate	ACATS #286	0 (no error)	18.1	18.1
Moderate	Modified Brazil C	0 (no error)	13.3	13.3
Moderate	Modified Brazil D	0 (no error)	12.6	12.6

Table 4. Susceptibility to Strongest Static Echoes

#### 4.5 Susceptibility to Single Dynamic Echoes at Varying Doppler Rates

The purpose of the multipath testing is to determine how robust is the LINX receiver in the presence of a single dynamic echo at varying Doppler rates with random noise injection.

The Doppler rate at TOV is recorded for each scenario of single echo power and delay.

All the multipath tests are done with the desired DTV signal RF level adjusted to the Moderate level (-53 dBm).

Signal Level	Echo Delay (ms)	Echo Power (dB)	C/N (dB)	Doppler Rate (Hz)	
				w/o. re-acq.	w. re-acq.
Moderate	-3	0	25	<b>2.0</b>	<b>0.0</b>
Moderate	-3	-3	25	<b>1.6</b>	<b>1.6</b>
Moderate	-3	-10	25	<b>23.0</b>	<b>21.0</b>
Moderate	3	0	25	<b>5.5</b>	<b>0.0</b>
Moderate	3	-3	25	<b>22.5</b>	<b>3.0</b>
Moderate	3	-10	25	<b>183.0</b>	<b>60.0</b>

Table 5. Susceptibility to Single Dynamic Echoes at Varying Doppler Rates

#### 4.6 Susceptibility to Dynamic Echoes in the Presence of Random Noise

The purpose of the multipath testing is to determine how robust is the LINX receiver in the presence of a dynamic echo in static multipath ensembles with random noise injection.

The echo power level at TOV is recorded for each multipath ensemble.

All the multipath tests are done with the desired DTV signal RF level adjusted to the Moderate level (-53 dBm).

Signal Level	Ensemble Type	Doppler Rate (Hz)	C/N (dB)	Echo Power (dB)	
				w/o. re-acq.	w. re-acq.
Moderate	CRC #1	1	25	<b>0(No error)</b>	<b>3</b>
Moderate	CRC #2	1	25	<b>0</b>	<b>3</b>
Moderate	CRC #3	1	25	<b>1</b>	<b>1</b>
Moderate	CRC #4	1	25	<b>Failed</b>	<b>¼</b>
Moderate	CRC #1	5	25	<b>1.5</b>	<b>5</b>
Moderate	CRC #2	5	25	<b>4</b>	<b>8</b>
Moderate	CRC #3	5	25	<b>11</b>	<b>Failed</b>
Moderate	CRC #4	5	25	<b>Failed</b>	<b>¼</b>

Table 6. Susceptibility to Dynamic Echoes in Presence of Random Noise

## 4.7 Receiver Equalizer Range

The purposes of these tests are to characterize the LINX receiver equalizer range.

### 4.7.1 Single Echo

The delay of a single echo is changed to determine the range over which the receiver equalizer operates without any noise injection.

Signal Level	Echo Power (dB)	C/N	Echo Delay (ms)	
			Minimum	Maximum
Moderate	-10	N/A	-29.5	38.5
Moderate	-3	N/A	-9.0	38.5
Moderate	0	N/A	-11.0 *	12.0 *

Table 7. Receiver Equalizer Range with Signal Re-acquisition

(\*: As there are two equal amplitude signals in this case, the time reference to zero is arbitrarily)

### 4.7.2 Pair Echoes

The delay of a pair of echoes (pre and post with a 1  $\mu$ s offset delay) are increased together to determine the range over which the receiver equalizer operates. No random noise added.

Signal Level	Echo Power (dB)	C/N	Echo Delay (ms)	
			Pre Echo	Post Echo
Moderate	-6	N/A	-14	15
Moderate	-3	N/A	-7	8

Table 8. Receiver Equalizer Range with Pair Echoes (Pre and Post) with Signal Re-acquisition

## 4.8 Single Echo Affecting Pilot

The purpose of this test is to determine the robustness of the carrier recovery of the LINX receiver. The phase of the single echo is adjusted to null out the VSB pilot.

The C/N is recorded for TOV with noise injection.

Signal Level	Ensemble Type			C/N (dB)	
	Delay	Amplitude	Phase	w/o. re-acq.	w. re-acq.
Moderate	Calibration			15.1	15.1
Moderate	3 $\mu$ s	0 dB	180°	19.7	19.7

Table 9. Susceptibility to Random Noise in presence of a Single Echo with Phase Adjusted to Null Out VSB Pilot

#### 4.9 NTSC interference into DTV

The purpose of this test is to determine the performance of the LINX receiver under NTSC lower, upper and co-channel interference. A test on single tone interference into DTV (adjusted to 2.5 MHz from the lower channel band edge) is also conducted.

The level of interference (D/U) at TOV is recorded for a typical undesired NTSC test signal (color bars). These tests are done with the DTV signal RF level adjusted to -53 dBm (Moderate) for co-channel interference and -68 dBm (Weak) for lower and upper adjacent channel interference.

Signal Level	Undesired NTSC and Tone Signal	C/N (dB)	D/U (dB)	
			w/o. re-acq.	w. re-acq.
Moderate	Co-channel	N/A	3.9	Failed
Moderate	CW at 205.5 MHz	N/A	3.7	Failed
Weak	Lower Adjacent	N/A	-43.7	-43.7
Weak	Upper Adjacent	N/A	-39.9	-39.9

Table 10. NTSC and Tone Interference into DTV

#### 4.10 Phase noise impairment

The purpose of this test is to determine the robustness of the LINX receiver to phase noise. The phase noise is created by injecting an FM modulated white noise at the local oscillator of the DTV modulator up-converter (IF to RF).

The DTV signal is adjusted and measured as for the interference testing. This test is done with the DTV signal RF level adjusted to -53 dBm.

The phase noise value is measured using an HP8560E spectrum analyzer with the phase noise measurement option. The phase noise level is increased until TOV is reached and measured in dBc/Hz at 0.1 kHz, 1 kHz, 2kHz, 5 kHz, 10 kHz, 20 kHz and 50 kHz at either side of the peak carrier.

Frequency offset (kHz)	Phase Noise (dBc/Hz)
0.1	-48.3
1	-58.0
2	-63.8
5	-71.7
10	-77.5
20	-83.7
50	-91.7

Table 11. Phase Noise Robustness at Moderate Level with Signal Re-acquisition

## 5 Conclusion

As a first generation prototype, the LINX receiver produces excellent results. The main results from the laboratory tests are summarized below:

1. The LINX receiver has a strong multipath capability. It can demodulate the signal under Brazil C, D and E multipath profiles.
2. The LINX receiver has much improved robustness against the pre-echo. It can withstand:
  - A -10 dB single echo within a delay range between  $-29.5 \mu\text{s}$  to  $+38.5 \mu\text{s}$ .
  - A -3 dB single echo within a delay range between  $-9.0 \mu\text{s}$  to  $+38.5 \mu\text{s}$ .
  - A 0-dB single echo over a  $12 \mu\text{s}$  range (Since there are two equal amplitude signals, time reference can not be selected).
3. The LINX receiver has a strong carrier recovery capability. It can acquire the signal even when the 8-VSB pilot was totally nulled out.

Improvement or fine-tuning of the receiver acquisition algorithm/software is needed to improve the signal acquisition under fast varying channel and co-channel NTSC interference. Further enhancement of the pre-echo performance and echo range may be useful as a longer equalization range might be needed for operation under the SFN environment.

## APPENDIX A

### MULTIPATH PROFILE DETAILS

Multipath Ensemble	Channel Simulator Parameter	Path 1	Path 2	Path 3	Path 4	Path 5	Path 6	
<b>Calibration</b>	Delay ( $\mu$ s)	0	OFF	OFF	OFF	OFF	OFF	
	Attenuation (dB)	0						
	Phase (degrees)	0						
<b>Brazil A</b>	Delay ( $\mu$ s)	0	0.15	2.22	3.05	5.86	5.93	
	Attenuation (dB)	0	13.8	16.2	14.9	13.6	16.4	
	Phase (degrees)	0	0	0	0	0	0	
<b>Brazil B</b>	Delay ( $\mu$ s)	0	0.30	3.50	4.40	9.50	12.70	
	Attenuation (dB)	0	12.0	4.0	7.0	15.0	22.0	
	Phase (degrees)	0	0	0	0	0	0	
<b>Brazil C</b>	Delay ( $\mu$ s)	0	0.089	0.419	1.506	2.322	2.799	
	Attenuation (dB)	2.80	0	3.8	0.1	2.5	1.3	
	Phase (degrees)	0	0	0	0	0	0	
<b>Brazil D</b>	Delay ( $\mu$ s)	0.15	0.63	2.22	3.05	5.86	5.93	
	Attenuation (dB)	0.1	3.8	2.6	1.3	0	2.8	
	Phase (degrees)	0	0	0	0	0	0	
<b>Brazil E</b>	Delay ( $\mu$ s)	0	1.0	2.0	OFF	OFF	OFF	
	Attenuation (dB)	0	0	0				
	Phase (degrees)	0	0	0				
<b>Special Brazil C</b>	Delay ( $\mu$ s)	0	0.089	1.506	1.506	2.322	2.799	
	Attenuation (dB)	2.80	0	20	0	2.5	1.3	
	Phase or Doppler	0°	0°	0.05 Hz	0°	0°	0°	
<b>Modified Brazil C</b>	Delay ( $\mu$ s)	0	0.089	0.419	1.506	2.322	2.799	
	Attenuation (dB)	2.80	0	3.8	Variable	2.5	1.3	
	Phase or Doppler	0°	0°	0°	0.05 Hz	0°	0°	
<b>Modified Brazil D</b>	Delay ( $\mu$ s)	0.15	0.630	2.22	3.05	5.86	5.93	
	Attenuation (dB)	Variable	3.8	2.6	1.3	0	2.8	
	Phase or Doppler	0.05 Hz	0°	0°	0°	0°	0°	
<b>CRC Dynamic</b>	Delay ( $\mu$ s)	0	-1.8	0.15	1.8	5.7	35	
	Attenuation (dB)	#1	0	20	20	10	Varied to reach TOV	18
		#2	0	17	17	7		15
		#3	0	14	14	4		12
		#4	0	11	11	1		9
Phase or Doppler	0	125°	80°	45°	1 or 5 Hz	90°		
<b>ACATS Ensemble A</b>	Delay ( $\mu$ s)	0	-1.8	0.15	1.8	5.7	18	
	Attenuation (dB)	0	20	20	10	Variable	18	
	Phase (degrees)	0	$\phi$ +288°	$\phi$	$\phi$ +72°	$\phi$ +144°	$\phi$ +216°	

**ACATS Ensemble A:** Where  $\phi$  is the phase of the shortest echo such that the null within the channel is offset with respect to the carrier (or pilot) frequency by +1.327320 MHz. Once the phase of the shortest delay is found, the phase of the other delay of the ensemble shall be: +72, +144, +216, and +288 degrees with respect to the shortest delay.

**Special Brazil C:** Echo Path 3 and 4 are assigned same delay (1.506  $\mu$ s), but different amplitude and phase. The Path 4 is 0 dB amplitude and 0 degree phase, while Path 3 is -20 dB amplitude and 0.05 Hz Doppler phase shift. The combined effect of Path 3 and 4 creates a flat fading environment so that the combined multipath amplitude goes higher and lower than 0 dB in a 0.05 Hz cycle.