

## 1 Introduction

The CMX998 has been proved extensively in TETRA 1 systems but there is an increasing need for higher data rates. This Application Note details measurements made using a CMX998 in a TETRA 2 system both as a proof of concept for TETRA 2 applications and for wideband applications in general. The evaluation is made using the CMX998 Evaluation Kit, the EV9980, with a small number of component changes.

## 2 Contents

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## 3 History

Version	Changes	Date
1	First Release	24-7-2013

## 4 TETRA 2

The main benefit of TETRA Release 2 (hereafter referred to as TETRA 2) is the increased data rates over the original TETRA 1 scheme but this is achieved at the consequence of increased radio spectrum (i.e. larger signal bandwidth). TETRA 2 mitigates the bandwidth requirement by using a number of QAM modulated sub-carriers that are summed together. The two nominal systems of TETRA 2 evaluated in this document are 50kHz QAM and 150kHz QAM.

### 4.1 Modulation Source Details

A SMIQ 02 is used to simulate TETRA 2 modulation because it doesn't have the capability to generate an exact TETRA 2 modulation as specified by ETSI. The TETRA 2 simulation is generated using 16 QAM modulation and a square root raised cosine filter with a Bt of 0.2. The symbol rate is set to achieve the correct bandwidth signal. With 50kHz QAM the symbol rate was 38.4kS/s and with 150kHz QAM the symbol rate is 115.2kS/s. In the following sections are results taken with the Rhode and Schwarz FESA30 of the SMIQ in the specified setup.

The above modulation setups were chosen to be representative of a TETRA 2 signal. In particular, the peak-to-mean of ~8dB is representative of a typical peak-limited TETRA 2 signal.

#### 4.1.1 50kHz QAM Source

The following plots show the 1<sup>st</sup> adjacent channel performance, eye diagram, constellation diagram and symbol/error table. The adjacent channel is measured as defined in the TETRA 2 standard [ref 2].

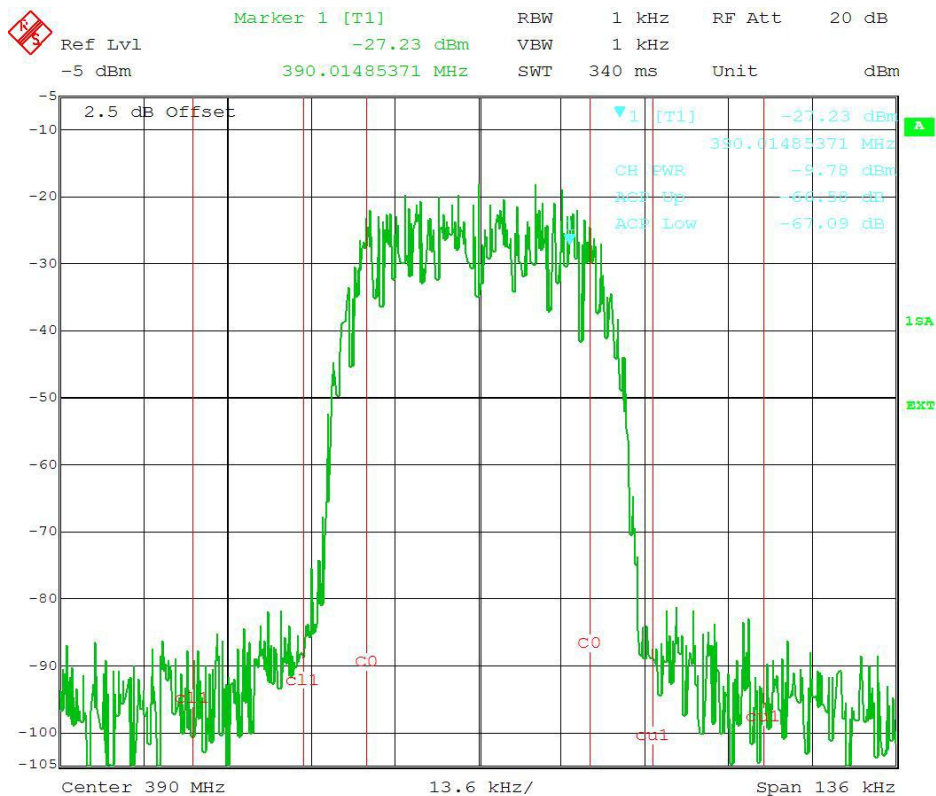


Figure 1. 50kHz QAM Source 1st Adjacent Channel Performance

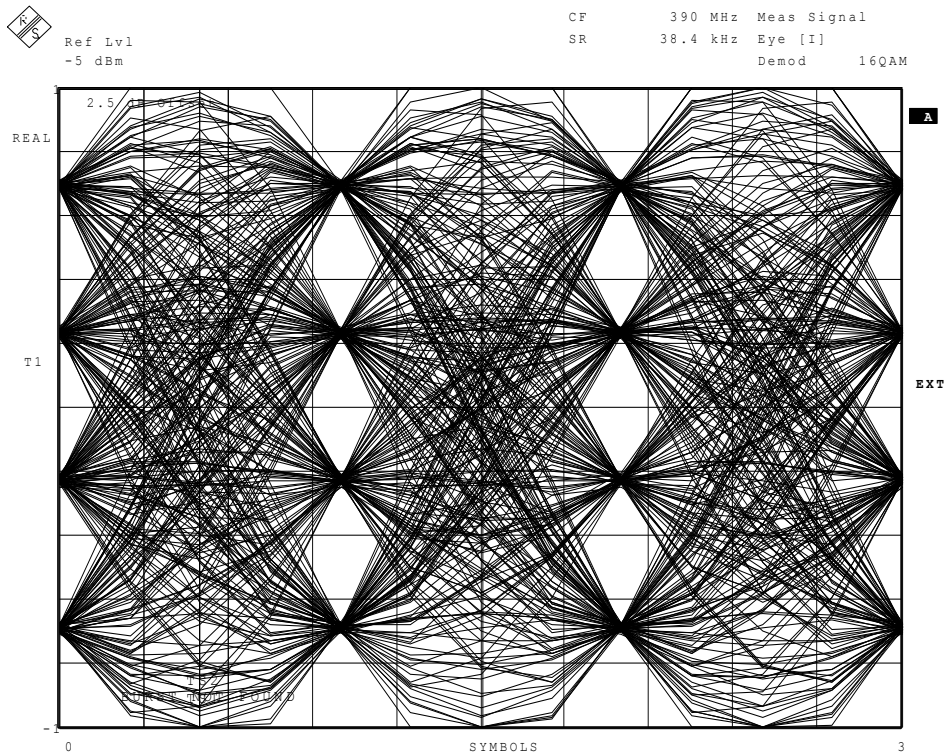


Figure 2. 50kHz QAM Source Eye Diagram



Figure 3. 50kHz QAM Source Constellation Diagram

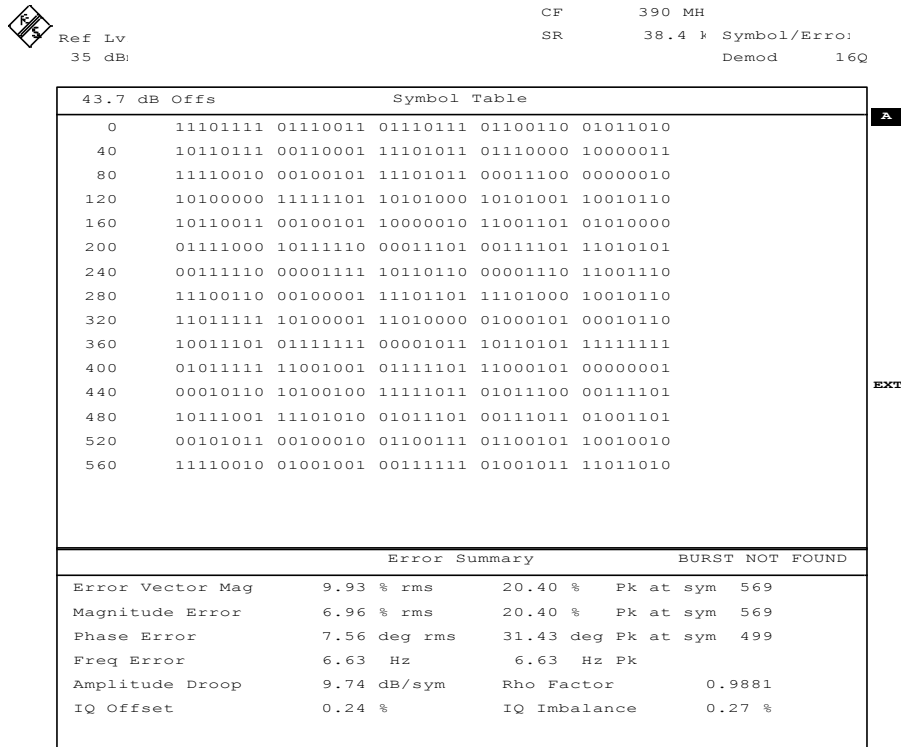


Figure 4. 50kHz QAM Symbol/Error Tables

4.1.2 150kHz QAM Source

The following plots show the 1<sup>st</sup> adjacent channel performance, eye diagram, constellation diagram and symbol/error table.

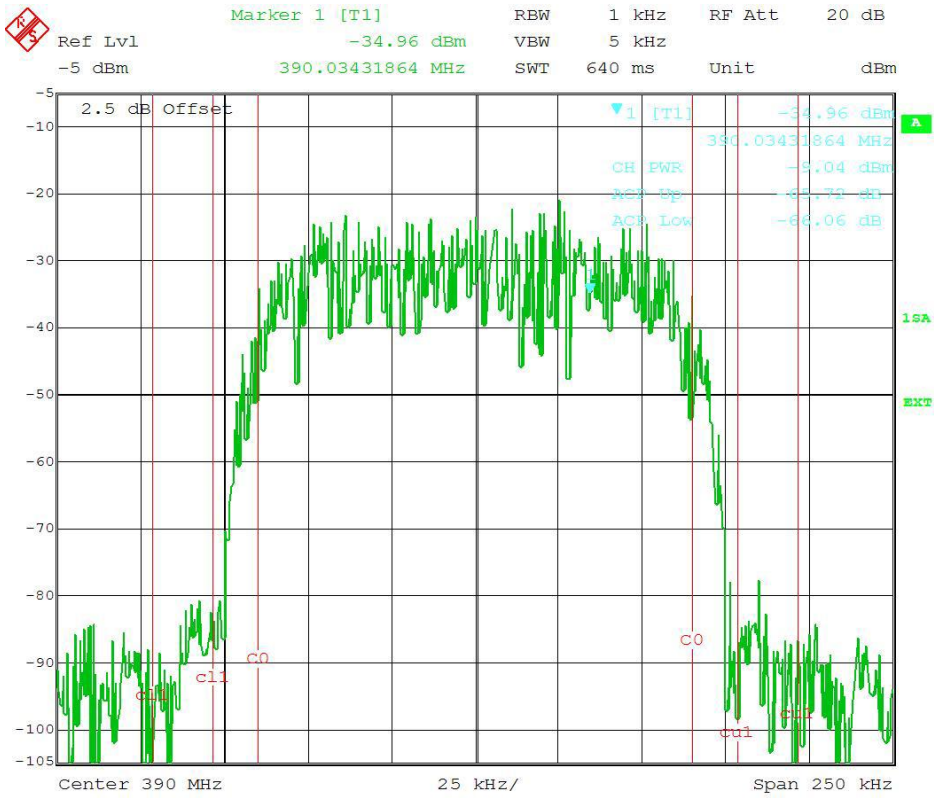


Figure 5. 150kHz QAM Source 1st Adjacent Channel Performance

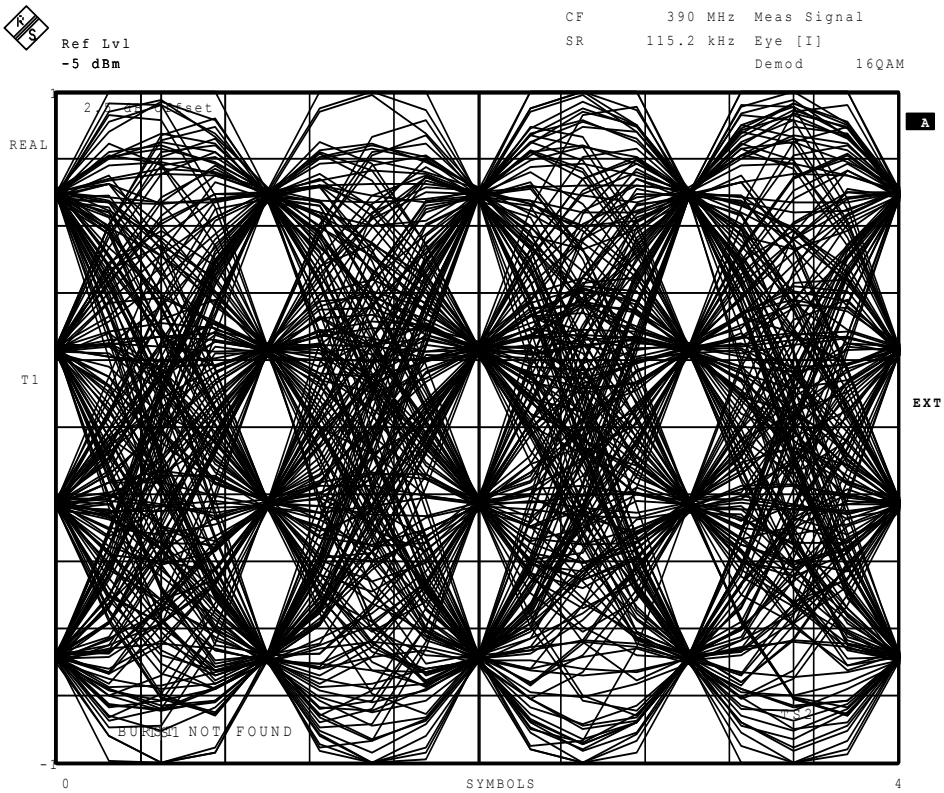


Figure 6. 150kHz QAM Source Eye Diagram

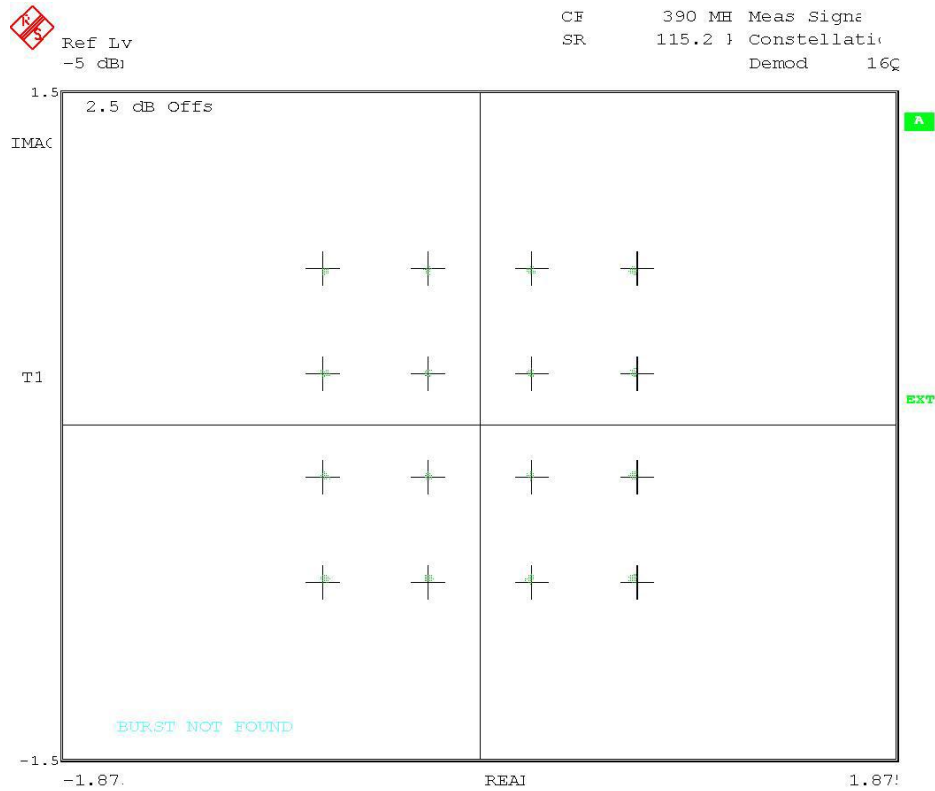


Figure 7 - 150kHz QAM Source Constellation Diagram

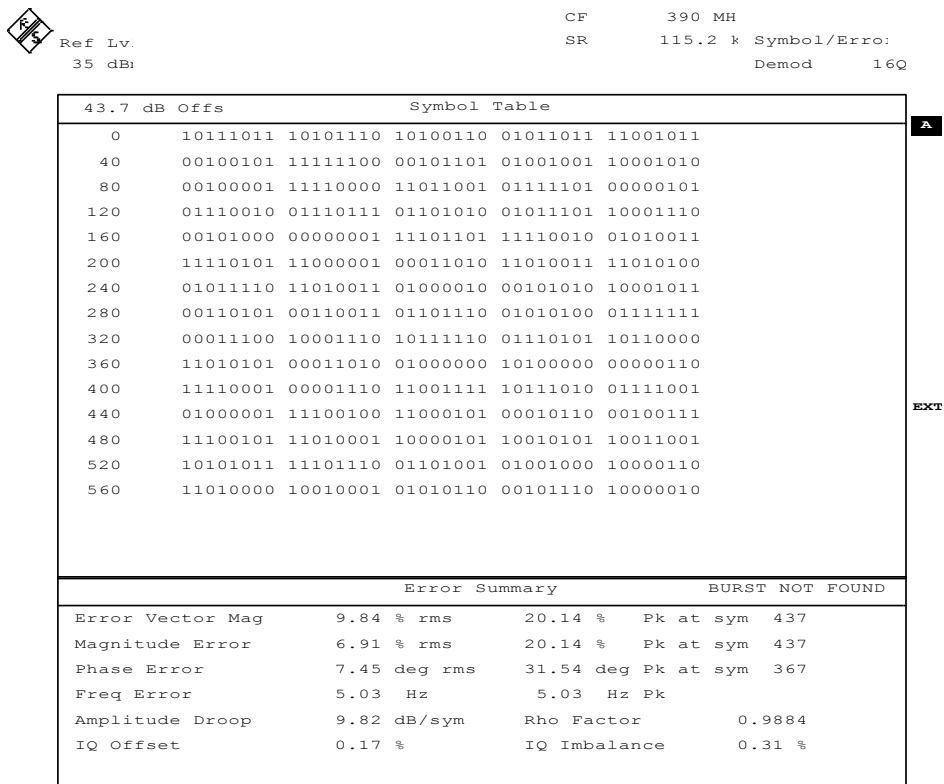


Figure 8 - 150kHz QAM Symbol/Error Tables

## 5 Measurement Results

### 5.1 50kHz QAM

The loop configuration is shown in Figure 9 using the CMX998 Cartesian Feedback Loop IC (CFBL) and the RF2175 PA device. The loop filter design used to obtain the results for 50kHz QAM is shown in Figure 10.

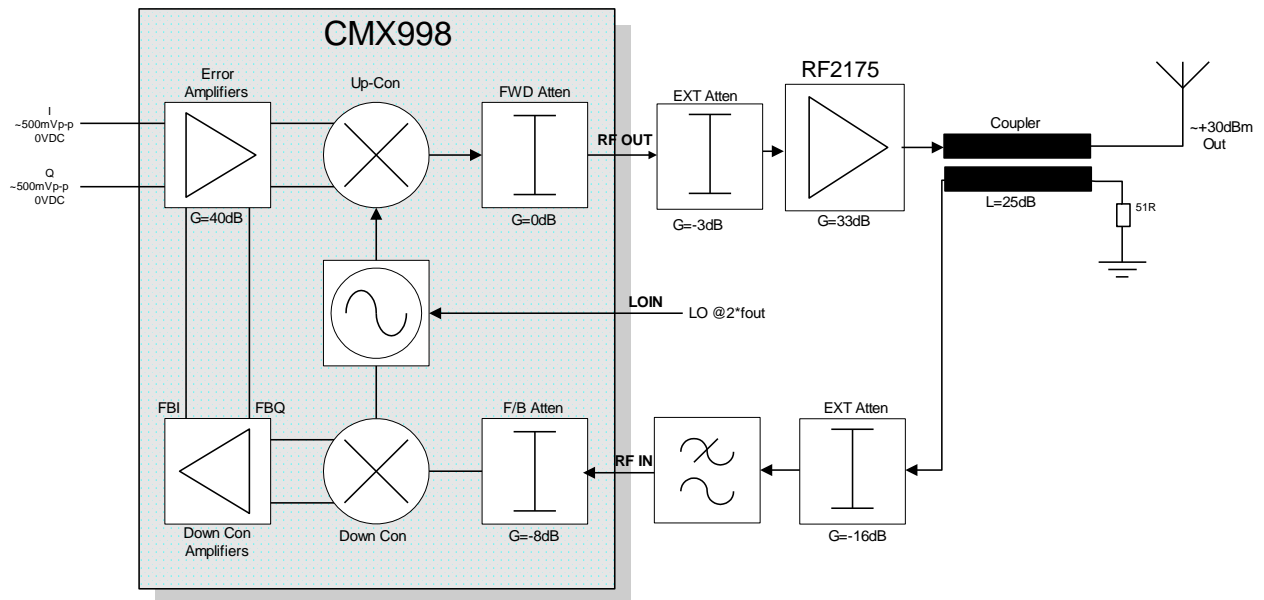


Figure 9 – Loop Configuration

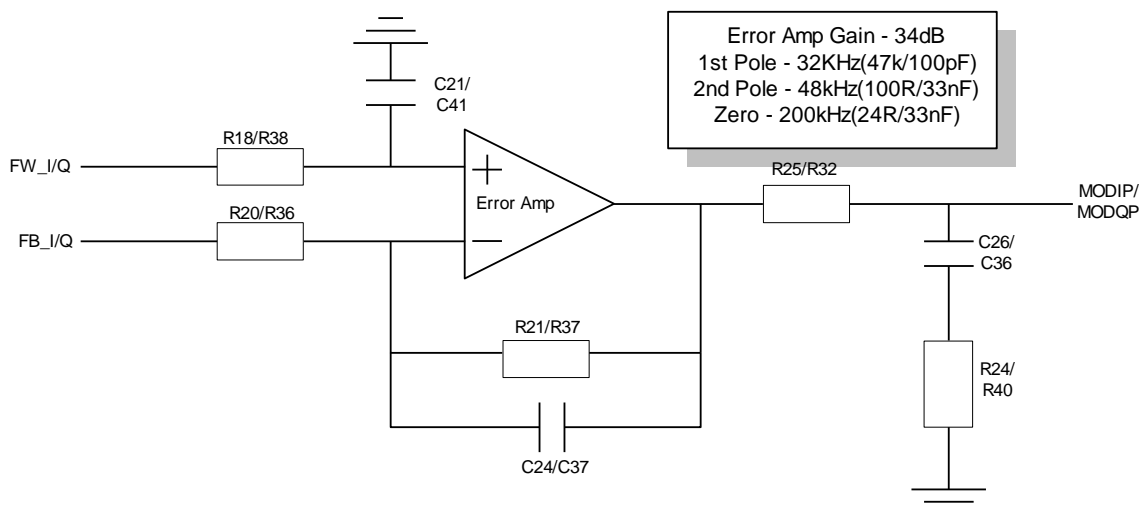


Figure 10 – 50kHz QAM Loop Filter Configuration

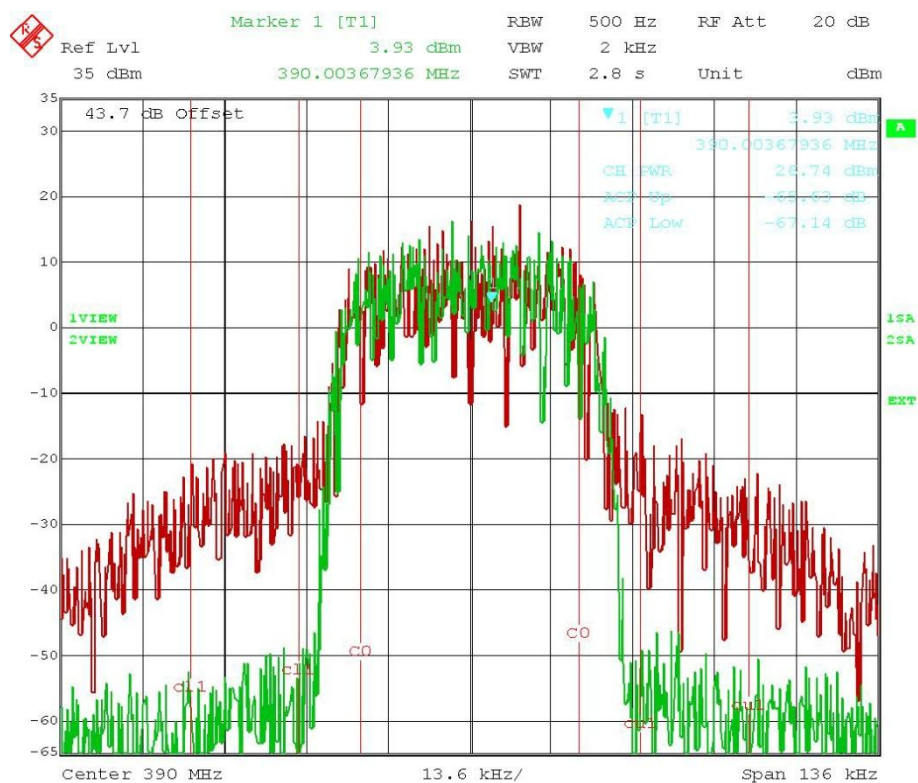
The loop filter is configured with an error amplifier gain of ~34dB. The 1st pole is at ~32kHz, the 2nd pole is at ~ 48kHz and the zero is at ~ 200kHz. With this configuration the following results are obtained. The plot in Figure 11 shows the comparison between the open and closed loop performance. The 1st Adjacent Channel is ~66/67dBc in closed loop which indicates ~30dB linearisation. The plots in Figure 13 and Figure 14 show the eye and constellation diagrams respectively. The vector error is ~11% which is comparable to the measurement of the source (see Figure 4). All measurements have been done at 390MHz with the LO at twice the frequency. In Table



1 are some wideband noise measurements for the 50kHz QAM setup and the TETRA 2 requirements have been included for comparison.

Offset (kHz)	Noise (dBc)	TETRA 2 Requirements (<3W) dBc
+112.5	-80	-68
-112.5	-78.3	-68
+262.5	-86	-72
-262.5	-85.3	-72
+500	-87.2	-78
-500	-85	-78
5000	-100	-95

**Table 1 - 50kHz QAM WBN measurements**



**Figure 11 – 50kHz QAM Closed and Open Loop Performance**



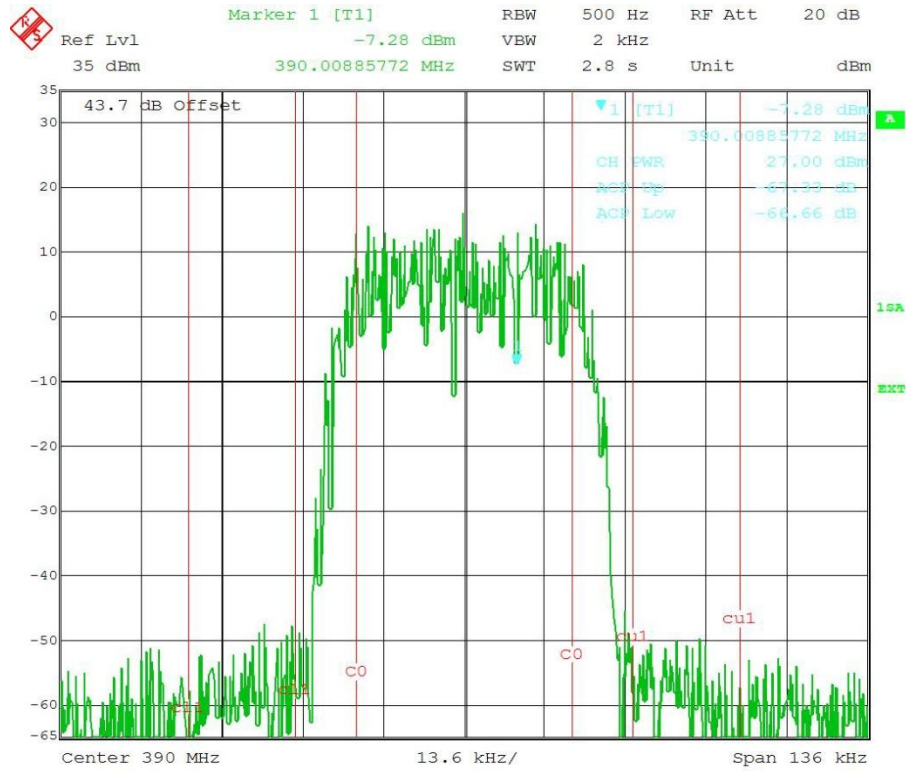


Figure 12 – 50kHz QAM 1<sup>st</sup> Adjacent Channel Performance

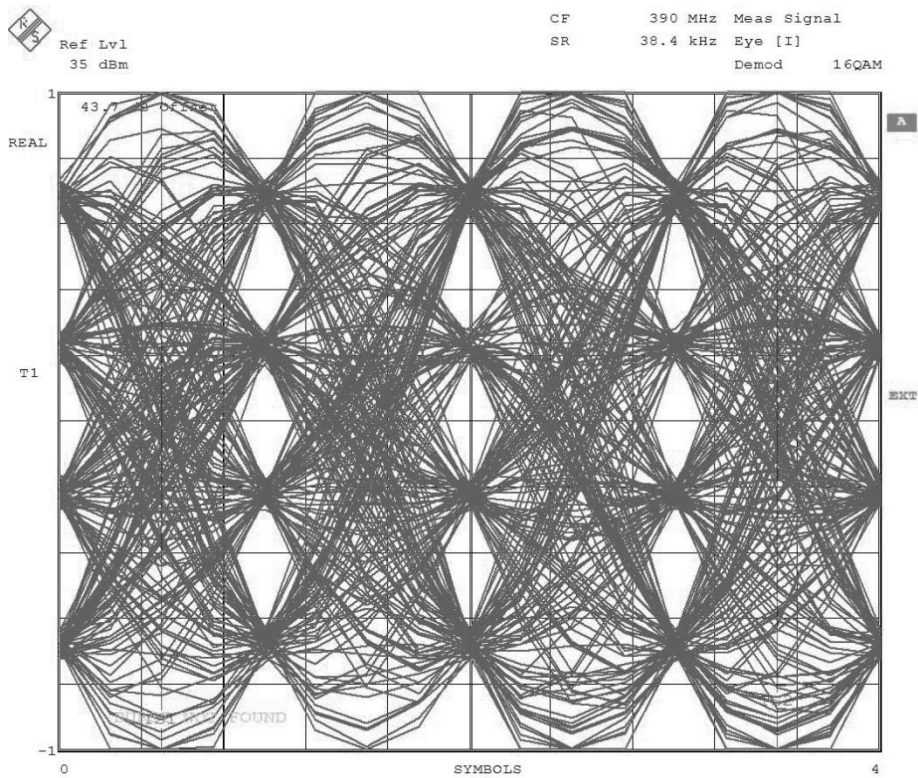


Figure 13 – 50kHz QAM Eye Diagram

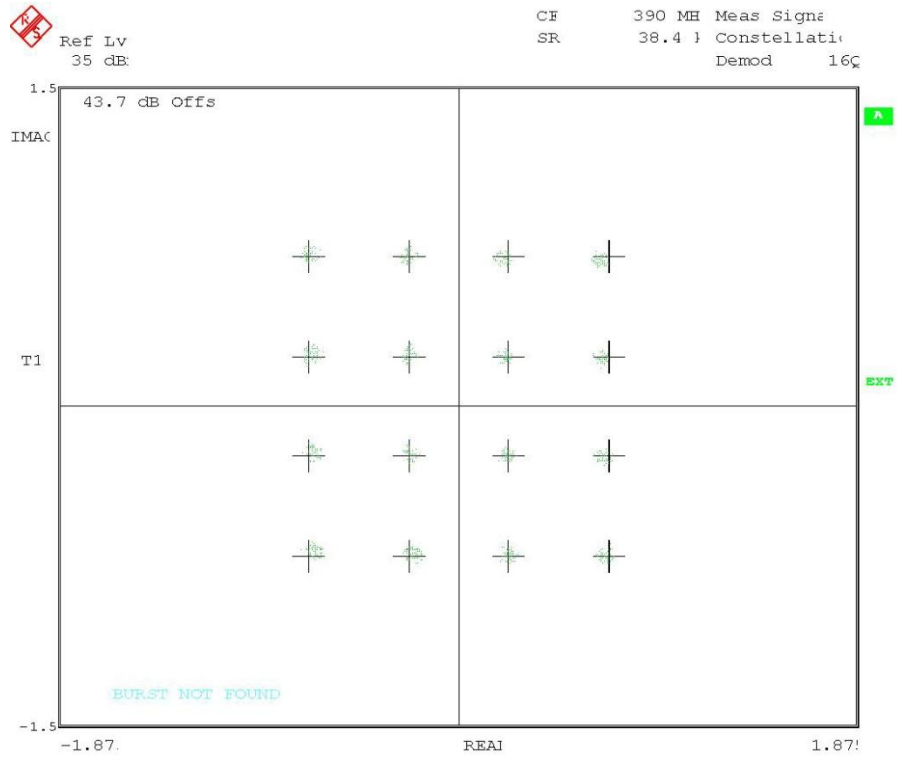


Figure 14 – 50kHz QAM Constellation Diagram

CF 390 MHz  
SR 38.4 k Symbol/Error:  
Demod 16Q

Ref Lv 35 dB

43.7 dB Offs

Symbol Table					
0	10000100	11011001	01101000	00000101	10111000
40	11111110	10101011	01101001	10000010	00001111
80	00010001	10100000	00001010	00001100	10010010
120	10001100	10101111	10111011	01100101	11100000
160	00011010	11000011	10000001	10010100	01011010
200	10000011	00011110	10000111	00010111	01110110
240	00100110	10101001	01110000	01111110	10010011
280	00001110	00011000	01010100	01101110	11010011
320	11000001	01011011	00011100	10011011	11101011
360	10111010	01101001	00010100	00101110	01001100
400	11010010	00010011	11101001	11110011	10010000
440	11011101	01100001	11110001	10001001	00100001
480	11111000	11101110	01100100	01111111	10011111
520	11111010	00101001	10001011	00111101	00000100
560	00100111	00101011	10010111	11000001	10011101

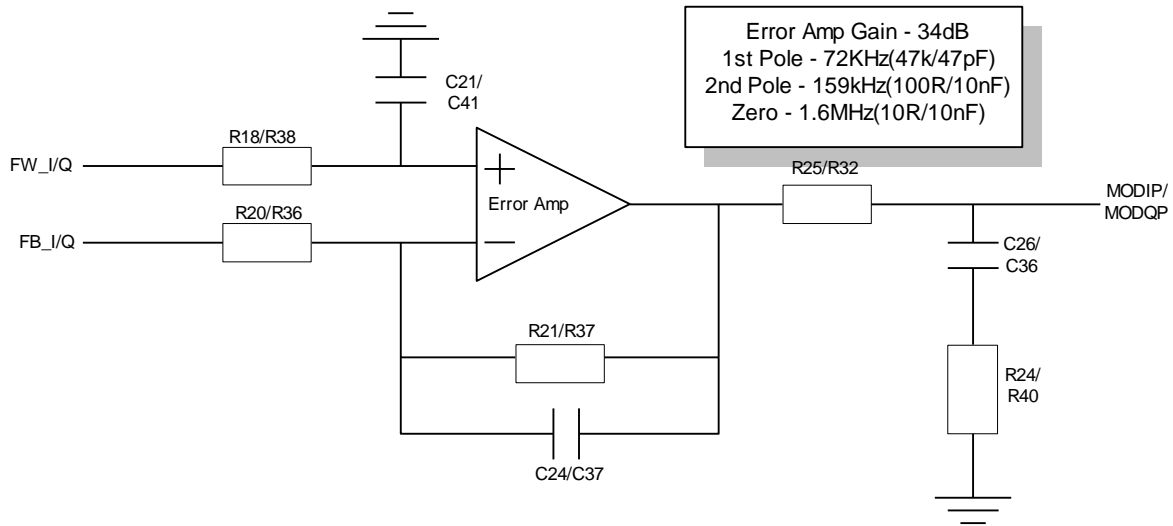
  

Error Summary		BURST NOT FOUND	
Error Vector Mag	10.26 % rms	22.17 %	Pk at sym 577
Magnitude Error	7.25 % rms	21.62 %	Pk at sym 507
Phase Error	7.61 deg rms	-31.79 deg	Pk at sym 948
Freq Error	-73.24 mHz	-73.24 mHz	Pk
Amplitude Droop	10.48 dB/sym	Rho Factor	0.9868
IQ Offset	0.05 %	IQ Imbalance	4.18 %

Figure 15 – 50kHz QAM Symbol/Error Table

### 5.2 150kHz QAM

The loop configuration is shown in Figure 9. The critical loop filter configuration is shown in Figure 16.



**Figure 16 - 150kHz QAM Loop Filter Configuration**

The loop filter is configured such that the error amplifier gain is ~34dB. The 1st pole is at ~72kHz, the 2nd pole is at ~ 159kHz and the zero is at ~ 1.6MHz. With this configuration the following results are obtained. The plots in Figure 17 and Figure 18 show the comparison between the open and closed loop performance. The 1st Adjacent Channel is ~64/65dBc in closed loop which indicates ~25dB linearisation. The plots in Figure 20, Figure 21 and Figure 22 show the eye diagram, constellation diagram and symbol/error table respectively. All measurements have been done at 390MHz with the LO at twice the frequency. Table 2 contains some wideband noise measurements for the 150kHz QAM setup and the TETRA 2 requirements have been included for comparison.

Offset (kHz)	Noise (dBc)	TETRA 2 Requirements (<3W) dBc
+162.5	-69	-60
-162.5	-70	-60
+312.5	-82.5	-63
-312.5	-82	-63
+562.5	-85.8	-70
-562.5	-85.1	-70
5000	-101	-95

**Table 2 – 150kHz QAM WBN measurements**

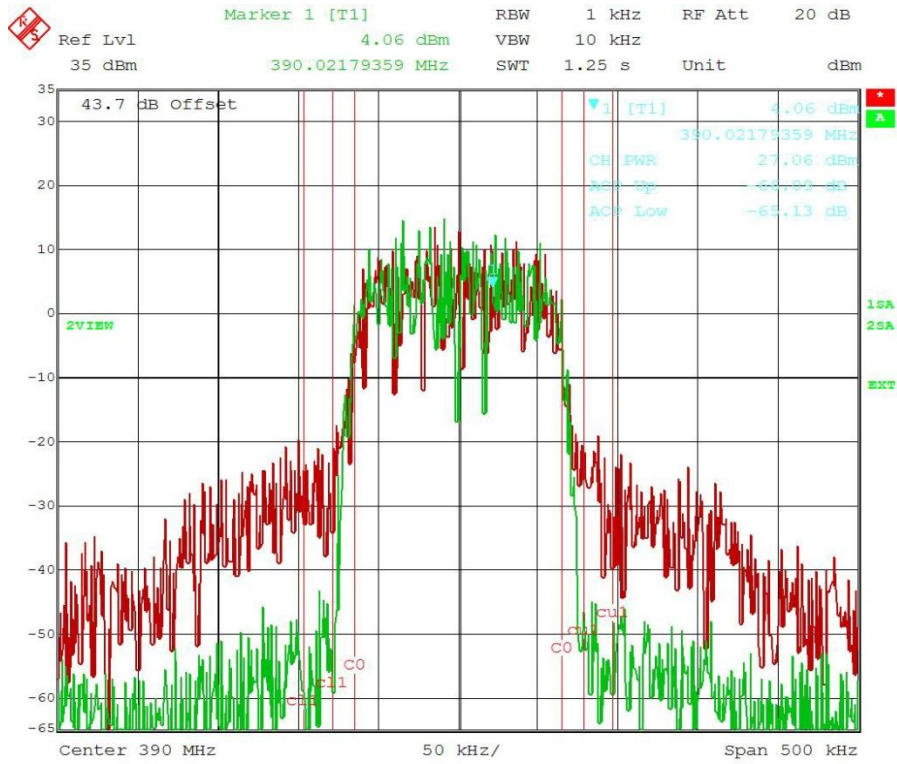


Figure 17 – 150kHz QAM Open and Closed Loop comparison

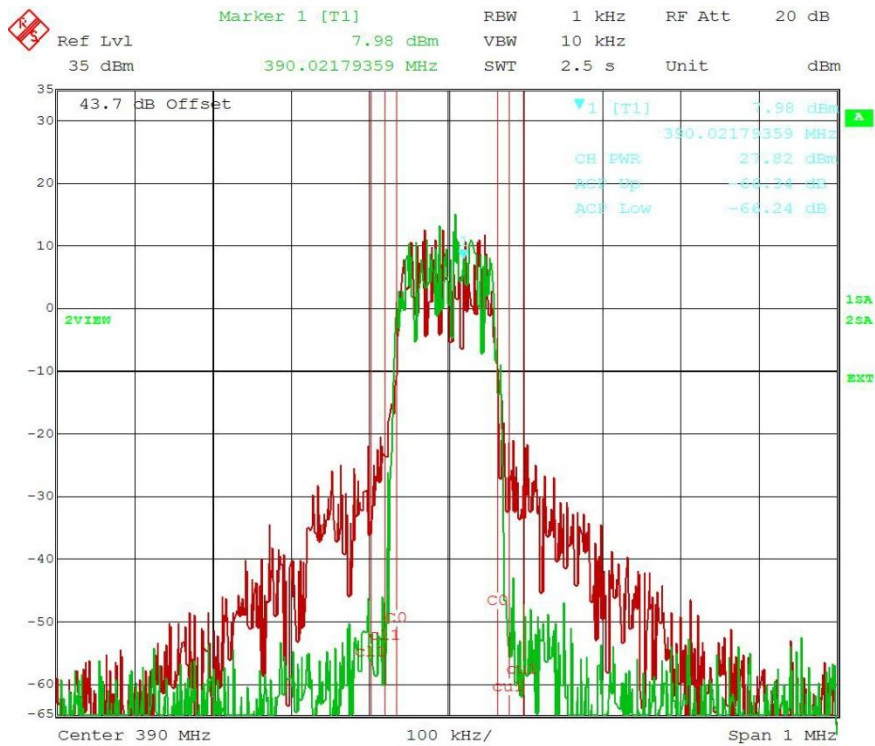


Figure 18 - 150kHz QAM Open and Closed Loop comparison with a wider span

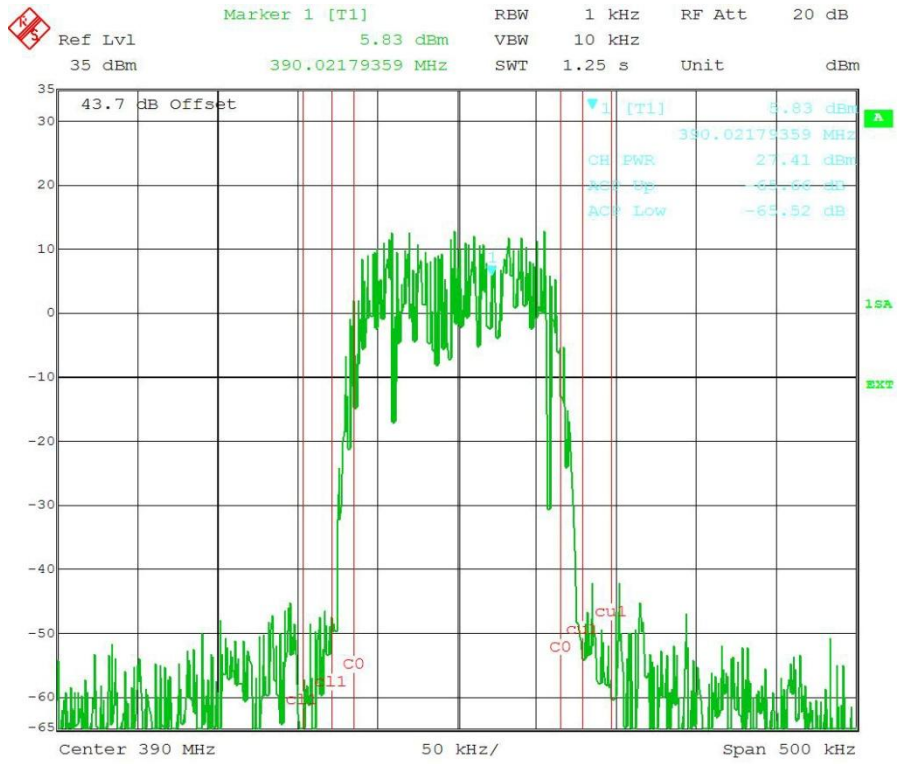


Figure 19 – 150kHz QAM 1<sup>st</sup> Adjacent Channel Rejection

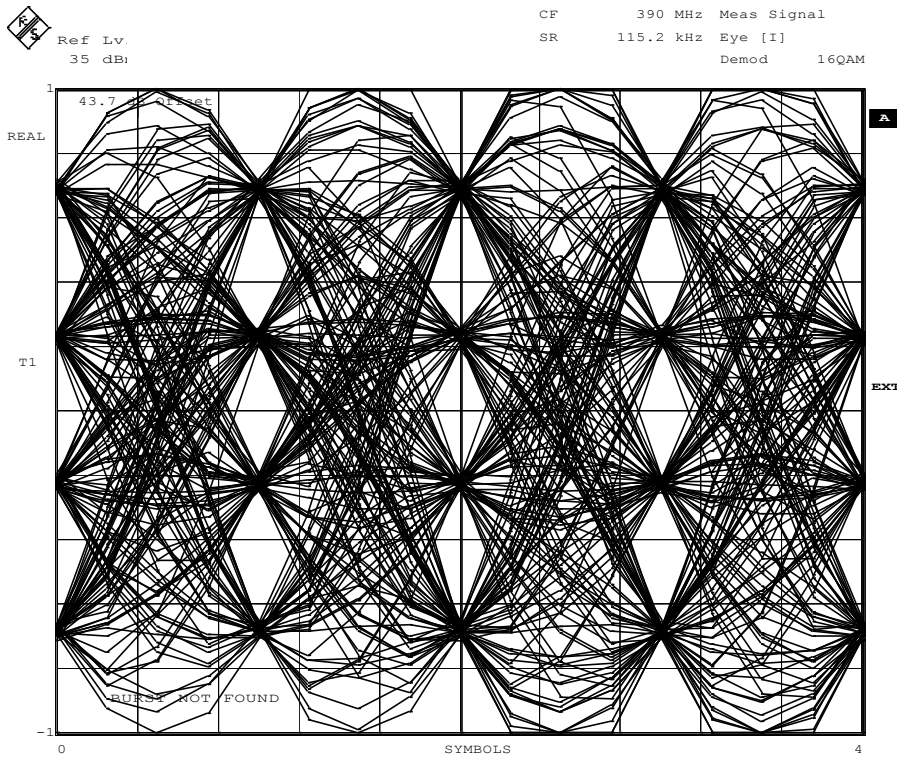


Figure 20 – 150kHz QAM Eye Diagram

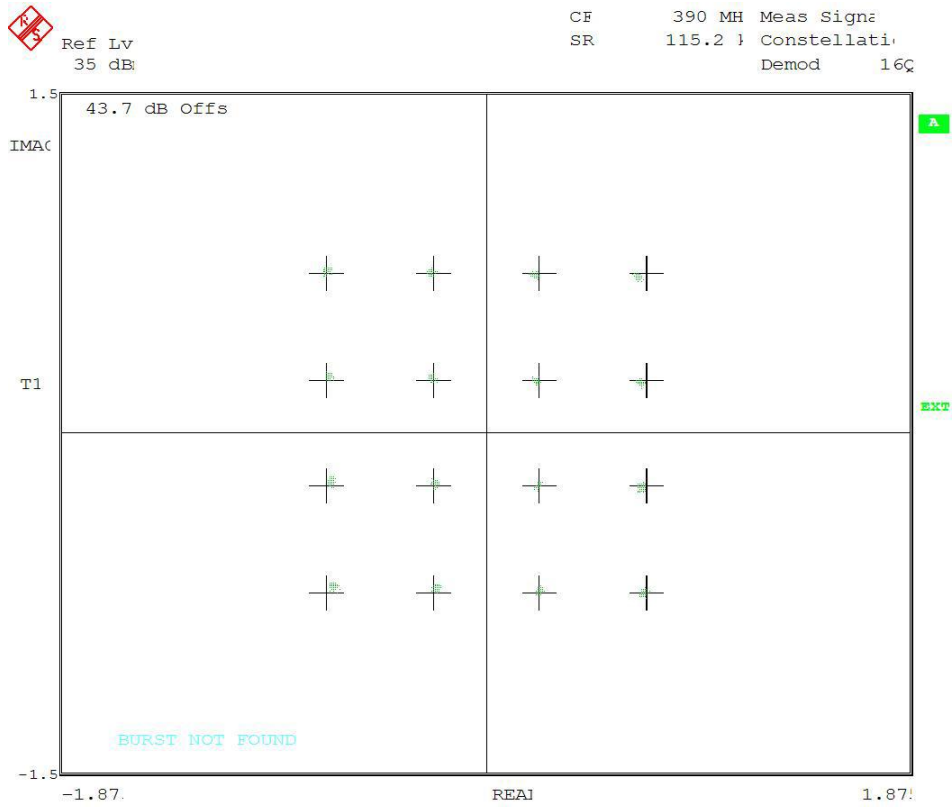


Figure 21 – 150kHz QAM Constellation Diagram

CF 390 MHz  
SR 115.2 k Symbol/Erro:  
Demod 16Q

Ref Lv 35 dB

43.7 dB Offs

Symbol Table					
0	10111111	11011100	11011101	10011001	01011010
40	11101101	11000100	10111110	11010000	00101100
80	11111000	10000101	10111110	01000011	00001000
120	10100000	11110111	10100010	10100110	01101001
160	11101100	10000101	00101000	00110111	01010000
200	11010010	11101011	01000111	11000111	01110101
240	11001011	00001111	11101001	00001011	00111011
280	10111001	10000100	10110111	10110010	01101001
320	01111111	10100100	01110000	00010101	01001001
360	01100111	11011111	00001110	11100101	11111111
400	01011111	00110110	11010111	00110101	00000100
440	01001001	10100001	11111110	01010011	11000111
480	11100110	10111010	01010111	11001110	00010111
520	10001110	10001000	10011101	10010101	01101000
560	11111000	00010110	11001111	00011110	01111010

Error Summary				BURST NOT FOUND	
Error Vector Mag	10.05 % rms	21.34 %	Pk at sym	34	
Magnitude Error	7.07 % rms	21.31 %	Pk at sym	34	
Phase Error	7.64 deg rms	-31.30 deg	Pk at sym	475	
Freq Error	-521.85 mHz	-521.85 mHz	Pk		
Amplitude Droop	10.17 dB/sym	Rho Factor	0.9875		
IQ Offset	0.06 %	IQ Imbalance	2.09 %		

Figure 22 – 150kHz QAM Symbol/Error Table

## 6 Conclusions

The results taken with the CMX998 demonstrate that, with changes to the loop filter, the CMX998 Cartesian feedback loop can linearise systems with 150kHz bandwidth signals very well (~25dB linearisation measured in these tests). The results in this document show that for both 50kHz and 150kHz QAM the 1<sup>st</sup> Adjacent Channel ETSI requirement of 55dBc can easily be met and that the wideband noise requirement of -95dBc (@5MHz offset) can be met with good margin.

## 7 References

- [1] CMX998 Data Sheet, Cartesian Feed-back Loop Transmitter, D/998/12 February 2013
- [2] ETSI TS 100 392-2 V3.6.1 (2013-05). Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI)



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