Application Note

CMX998 with an RF5110G Power Amplifier

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1 Introduction

This document is intended as an aid to customers developing linear transmitters using the CMX998 integrated circuit[1] by demonstrating a typical 'Cartesian Loop' transmitter solution using 'off-the-shelf' components. A test environment using the CMX998 Cartesian Feedback Loop (CFBL) IC and the CMX981 Advanced Digital Radio Baseband Processor IC[2] is described. A Texas Instruments TMS320VC5510 DSK controls the CMX981. The CMX981 is used to generate π/4-DQPSK modulation as is used in the TETRA standard (ref [3]). It should be noted that this modulation is used as an example and the CMX998 is capable of being used with many other modulation schemes and international standards.

The test system described is used to linearize a power amplifier module from RF Micro Devices, the RF5110G[4]. Tests are conducted at 800MHz and 400MHz. The design uses entirely RoHS compliant components.

Familiarity with the CMX998 and CMX981 datasheets is encouraged to increase the level of understanding of the information in this application note.

Table of Contents

2 Hardware Configuration

The test setup uses the EV9980 CMX998 CFBL Evaluation board, the EV9810 CMX981 baseband processor evaluation board and a Texas Instruments TMS320VC5510 DSK. The diagram in Figure 1 indicates the connections made between the boards.

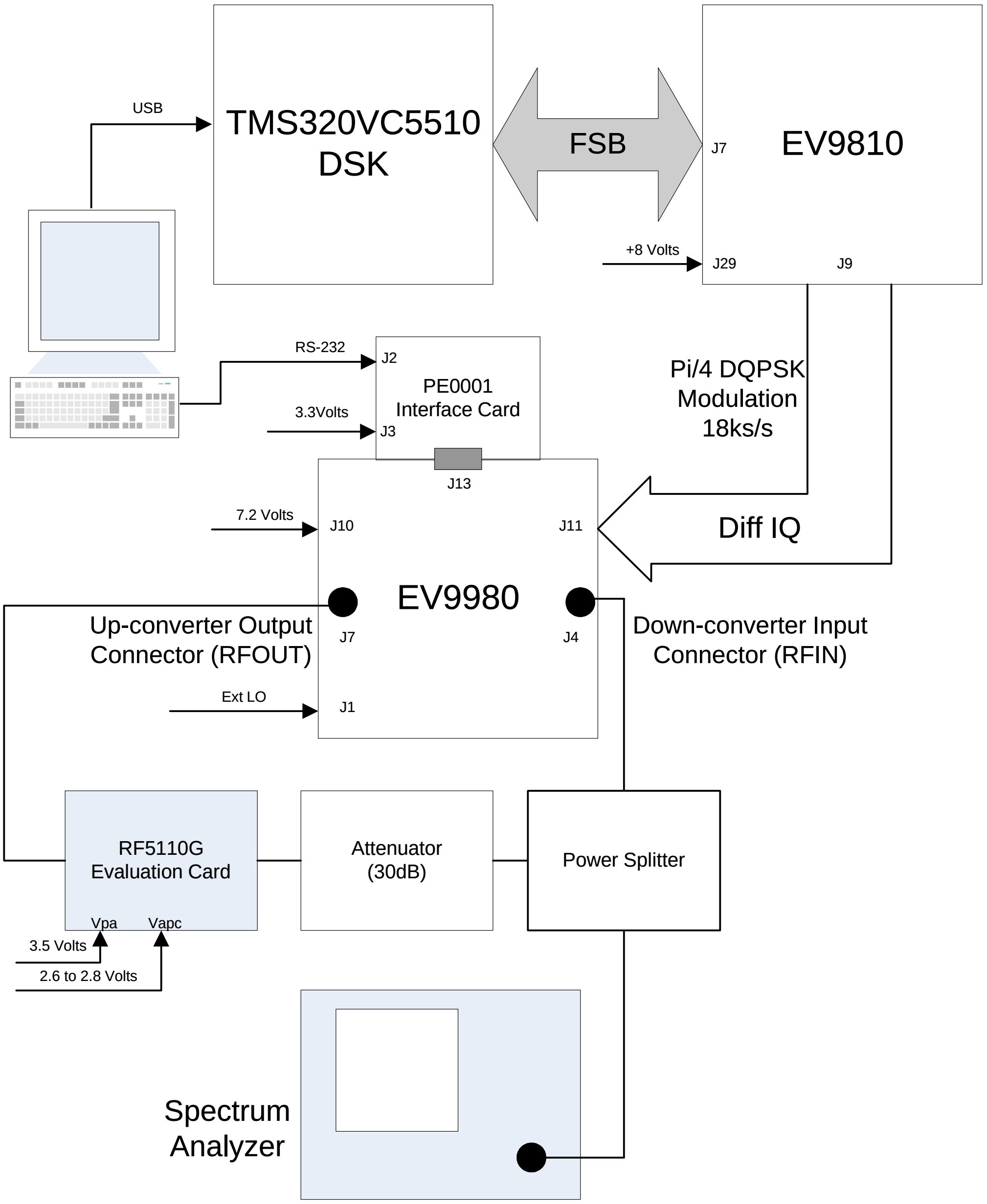


Figure 1 - Test Setup for RF5110G Evaluation with CMX998

2.1 Interconnections

A PC controls the system. The CMX998 is controlled via the PE0001 card and the CMX981 via the TMS320VC5510 DSK. The connections between the EV9810 and EV9980 are differential I and Q signals.

The power amplifiers on the EV9980 PCB are not used[1]. The output from the CMX998 up-converter is connected to the RF5110G evaluation card (EV9980 RFOUT, connector J7). The amplified output is then attenuated and split to the spectrum analyzer (to measure results) and the CMX998 down-converter input (EV9980 RFIN, connector J4). The attenuation between the RF5110G output and the spectrum analyzer input was measured and corrected in all measurements (attenuator, splitter and cable losses). A signal generator provided a -10dBm local oscillator signal to the CMX998 (J1 EV9980 LO-In).

2.2 CMX998 Input and Filter Amplifiers

The input amplifiers on the CMX998 were configured as Figure 2, to allow the EV9980 to interface directly to the EV9810. *(This arrangement is different from that used and shown in the EV9980 Datasheet– this scheme gives a better dc level based on BVREF).*

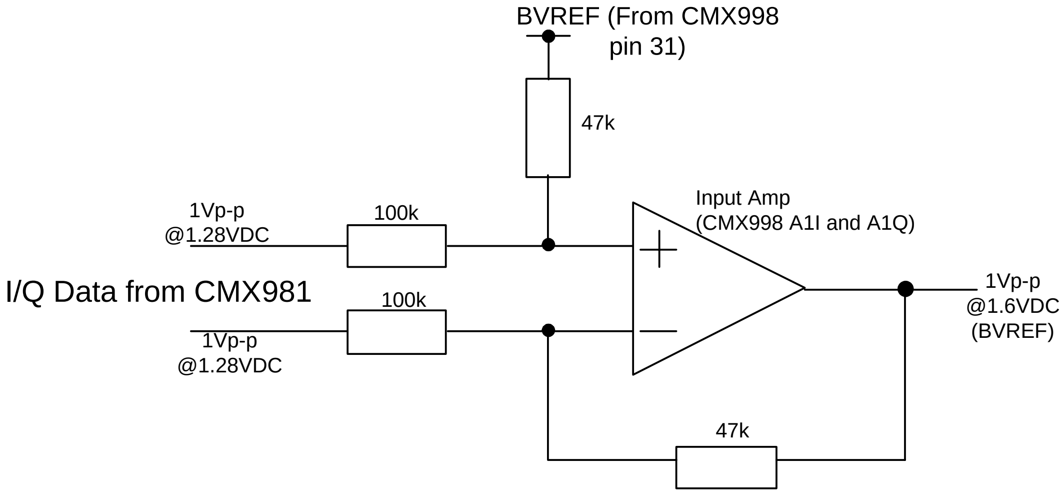


Figure 2 - CMX998Input Amplifier Configuration

The CMX998 filter amplifiers have been configured with a low pass Sallen-Key topology that has a 3dB bandwidth of ~50kHz (this is the standard configuration fitted to EV9980 cards).

[1] C27=NF, C30=1nF, C35=1nF, C54=1nF, C55=NF, R29=0R

2.3 CMX998 Error Amplifier

The error amplifier configuration used in the tests is the standard EV9980 setup and is shown in Figure 3. The 1st Pole is at ~16kHz, the 2nd Pole is at ~32kHz and the Zero is at ~320kHz.

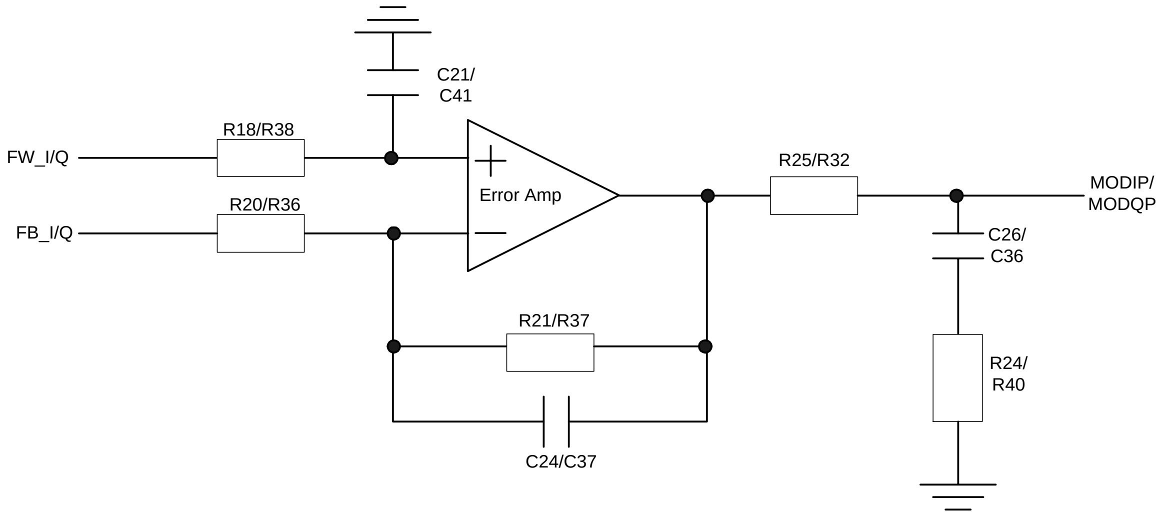


Figure 3 – Error Amplifier Configuration

2.4 400MHz Tests

For the 400MHz tests, the harmonic filter on the EV9980, which is normally in the feedback path from the coupler, was moved to the RFIN input path with the following changes:

R33 =8.2pF (Capacitor)
R29 = 18nH (Inductor)
R34 = 8.2pF (Capacitor)

3 RF5110G Performance

The following section details performance of the RF5110G measured ‘stand alone’ (i.e. driven from test equipment not the CMX998).

In all tests in this document the RF5110G power supply was +3.5 V.

3.1 Default Test PCB Configuration

The following plots show measured performance of the un-modified RF5110G evaluation card. It will be noted in Figure 4 that the characteristic is not very linear even before the onset of gain compression. The circuit has good gain at lower frequencies as well as the design frequency (850-900MHz) however when the input level is raised it is clear that the output at lower frequencies rapidly goes into compression indicating the device needs to be re-matched for UHF operation.

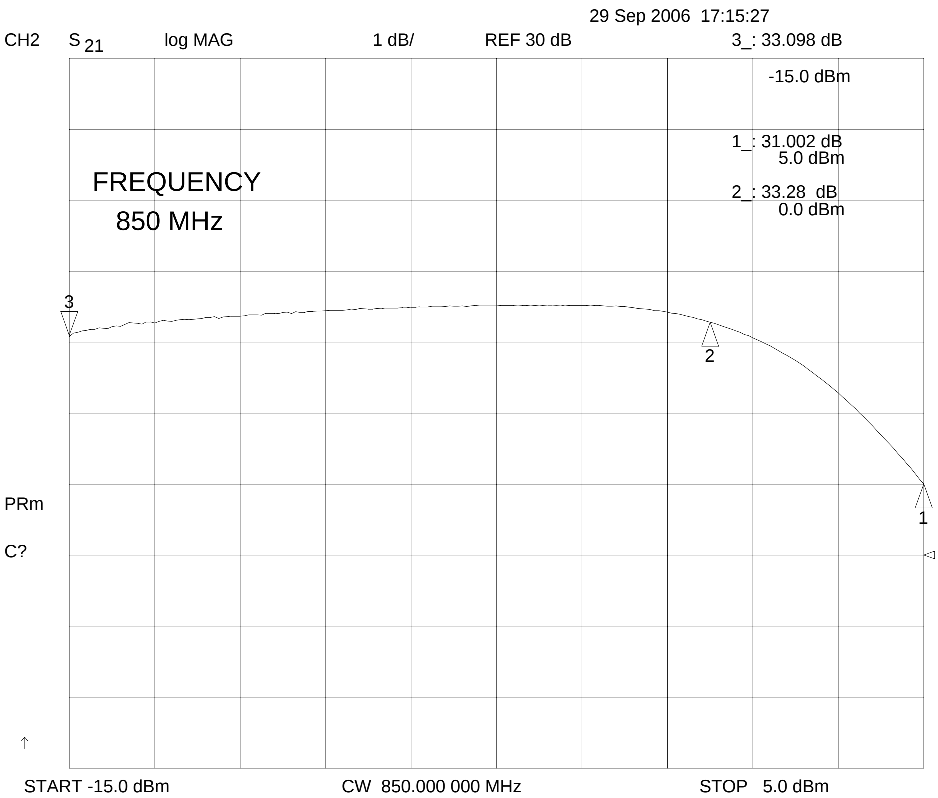


Figure 4 - Gain Compression Characteristic of RF5110G

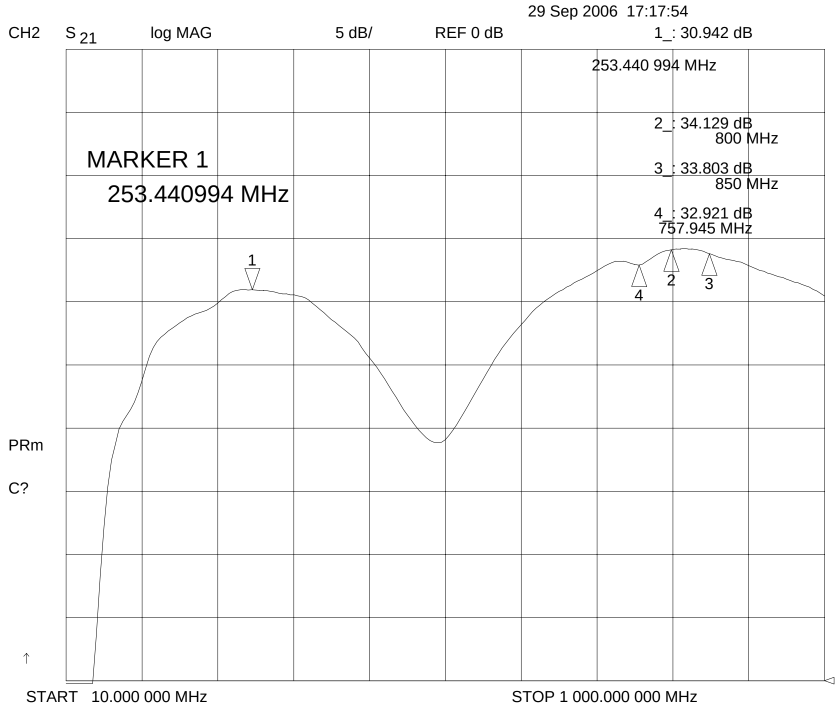


Figure 5 - Gain vs Frequency response of RF5110G Evaluation Card, input power -15dBm

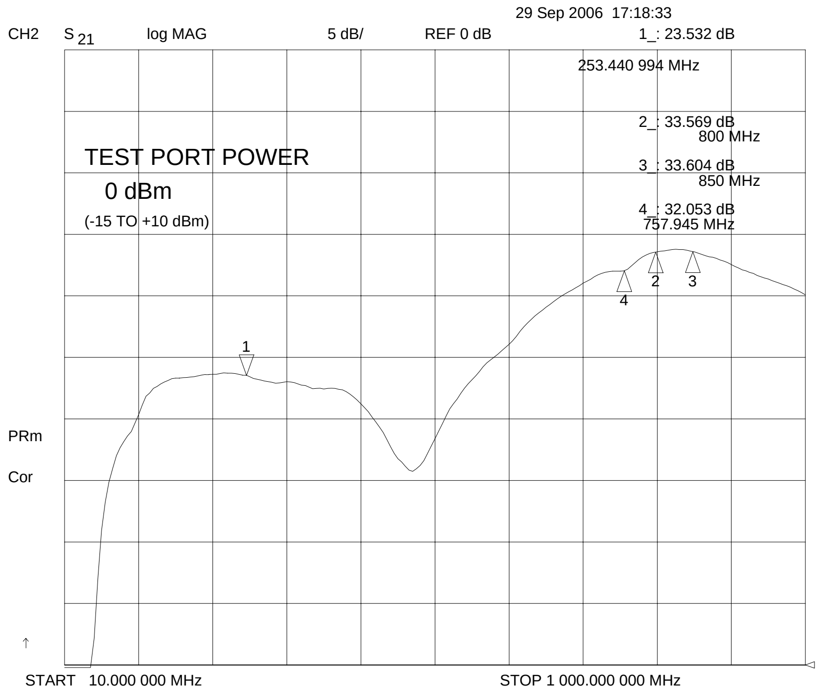


Figure 6 - Gain vs Frequency response of RF5110G Evaluation Card, input power 0dBm
(note gain compression at lower frequencies)

The linearity of the RF5110G can be adjusted depending on the Vapc voltage. It was noticed that third order products could be optimized at Vapc=2.6V to 2.7V. However this results in higher levels of high order products. As a result it was concluded that Vapc=2.8V is about the optimum control voltage.

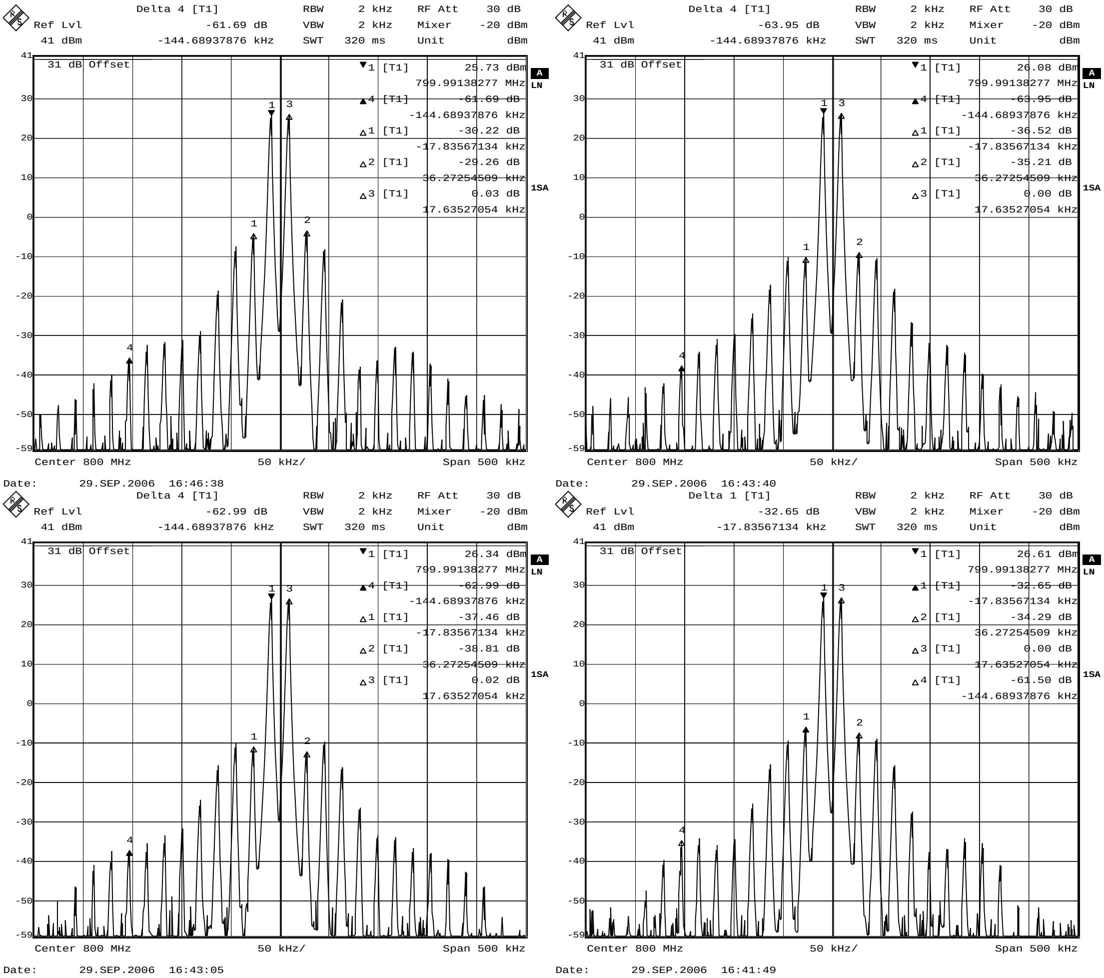


Figure 7 – PA Linearity with two-tone input for Vapc=2.5V (top left), 2.6V (top right), 2.7V (bottom left) and 2.8V (bottom right)

3.2 Re-matched for 400MHz Operation

The RF5110G matching was altered to optimize the performance for 400MHz, changes to the output match are shown in Figure 10. Other changes to decoupling recommended in the device datasheet[4] were also implemented.

It was found that at 400MHz the device has rather high gain but the compression point is somewhat less than what was achieved at 800/900 MHz. This can be seen in Figure 9. The saturated output was around +34dBm. Although it may be possible to achieve slightly more output power this was felt to be sufficient for the present tests of a 1W (mean) transmitter.

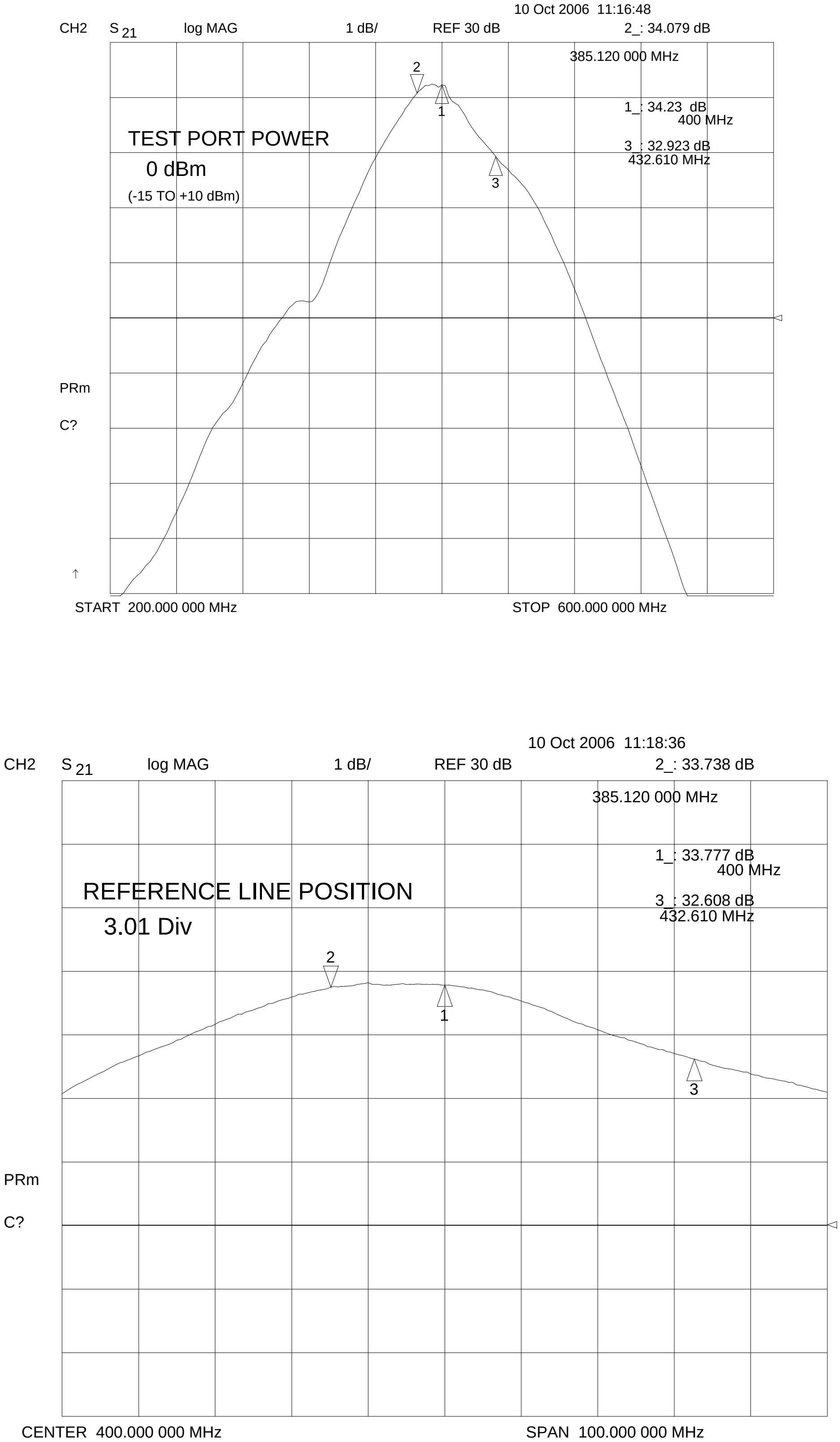


Figure 8 – Two plots of the response of RF5110G re-matched for 400MHz operation. The lower plot input power is +1dBm.

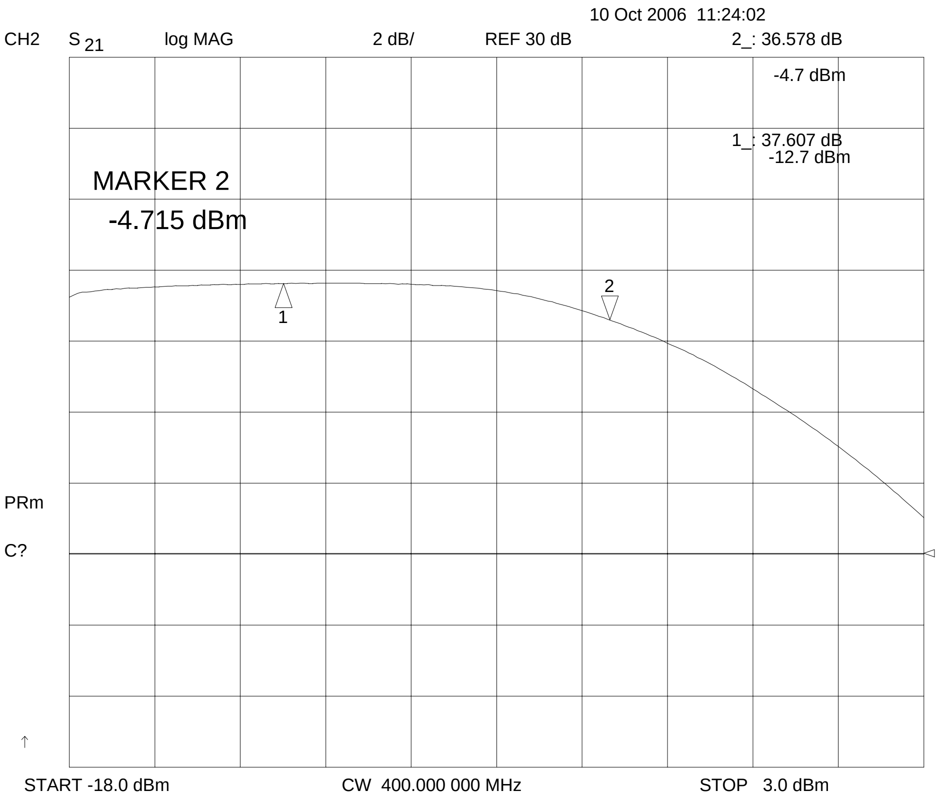


Figure 9 - Gain compression response of RF5110G at 400MHz

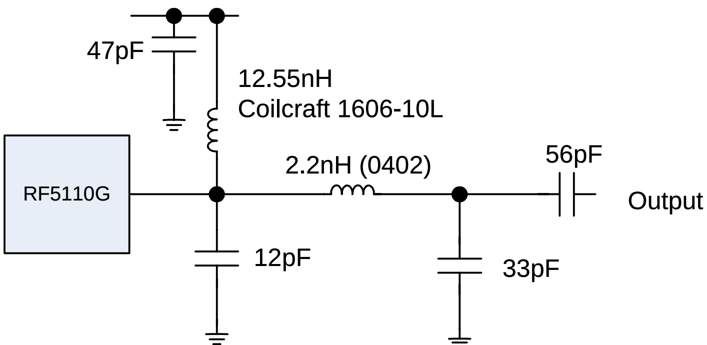
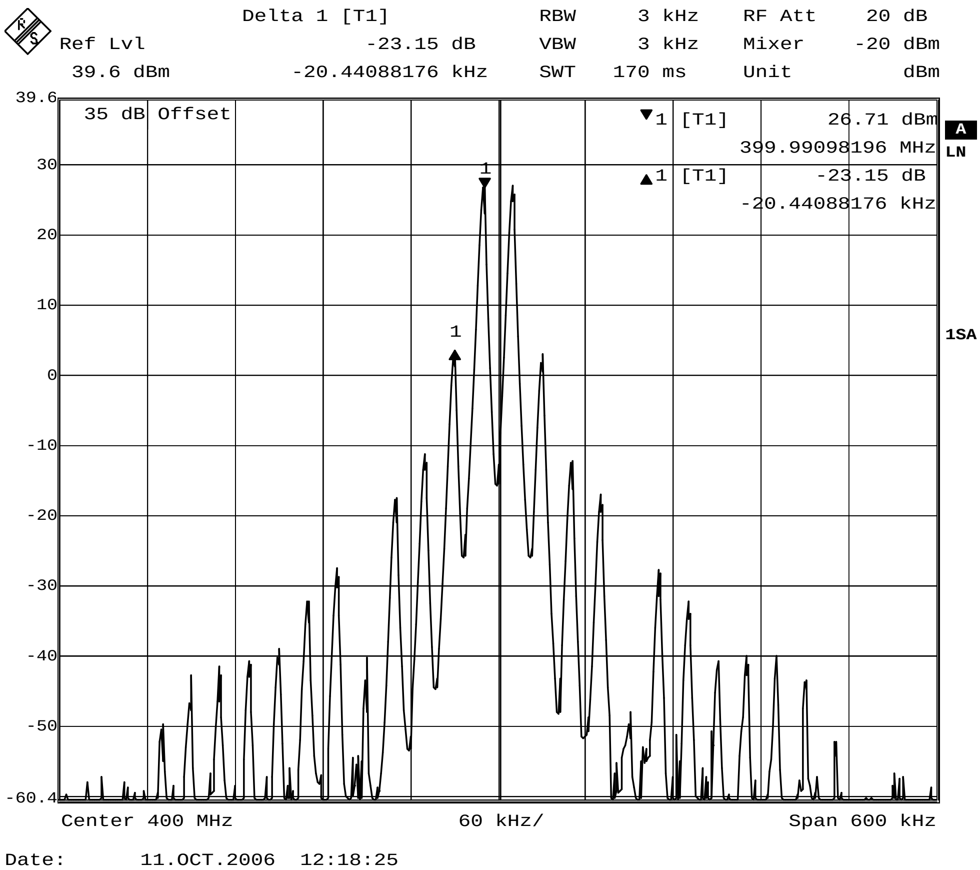


Figure 10 - Output matching of RF5110G for 400MHz operation



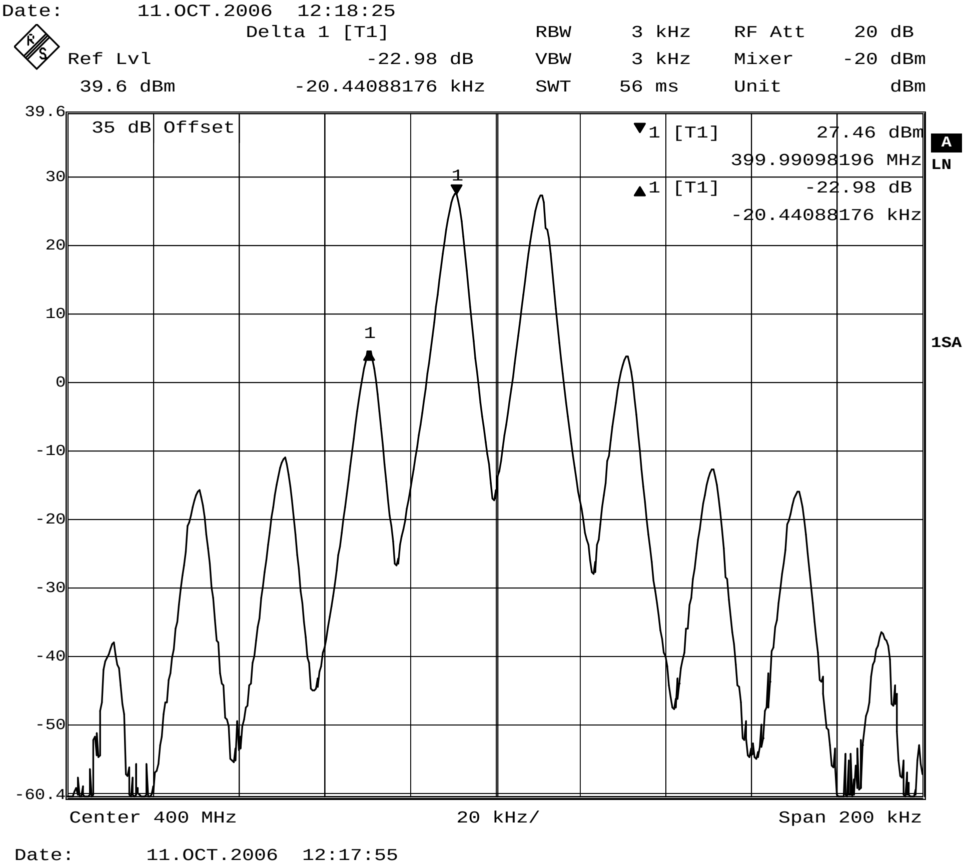


Figure 11 – RF5110G linearity at +33dBm PEP, Vapc=2.8V, Vdd=3.5V; note - Some cancellation of IMD products is present in the upper plot. This effect varies with Vapc.

4 CMX998 and RF5110G

4.1 Operation at 800MHz / 850MHz

The CMX998 was tested with the un-modified RF5110G evaluation card using the configuration shown in section 2. The RF5110G bias voltage (Vapc) was 2.8V and power supply was 3.5V.

4.1.1 Results at 850MHz

Results are shown in Figure 12 and Table 1 confirming the system provides excellent linearity and wideband noise performance compliant with TETRA requirements[3] (see also Table 2).

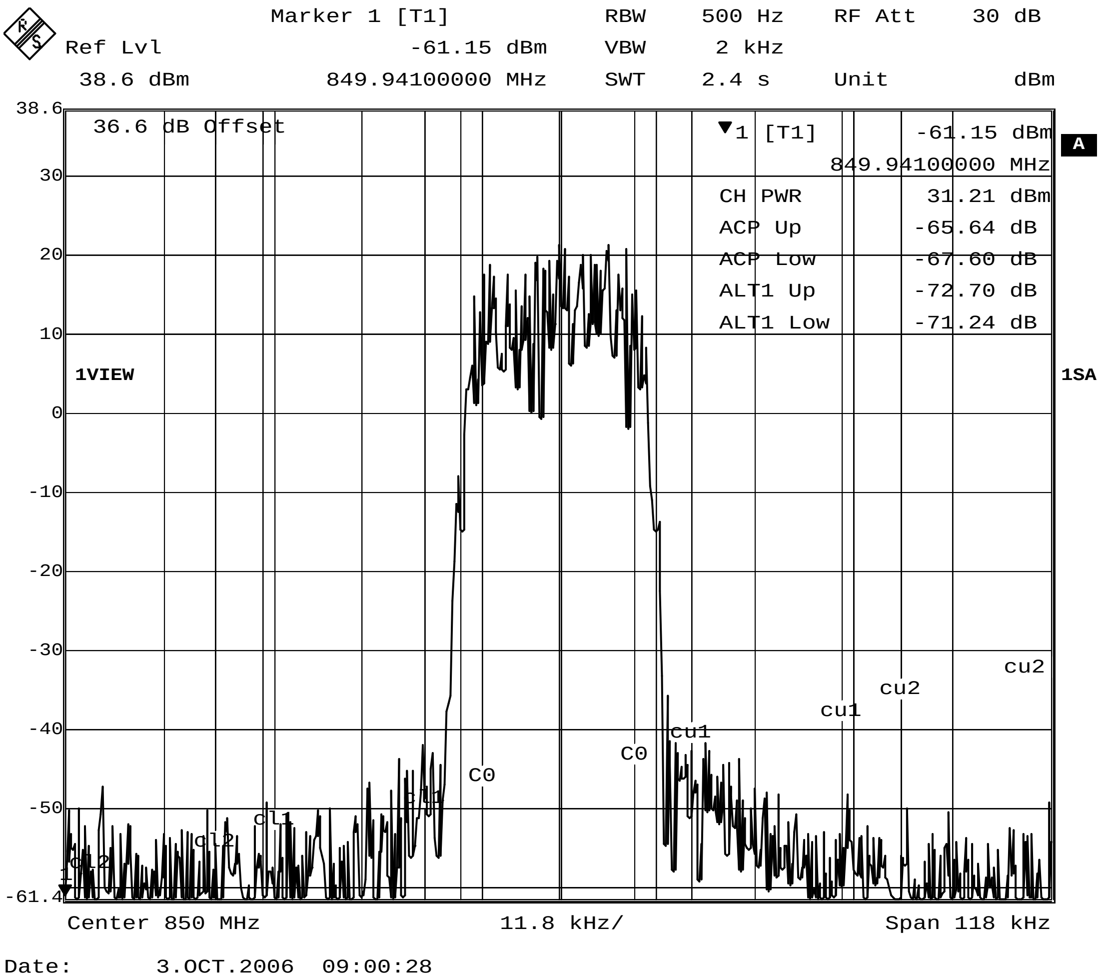


Figure 12 – CMX998 with RF5110G, adjacent and alternate channel performance at 850MHz

Table 1 shows measurement results of the noise at offset frequencies and compares them to TETRA specification points. All noise measurements were done with a mean output power of +30dBm (+33dBm PEP).

Offset (kHz)	**Noise (dBc/Hz)**	**TETRA Requirements (1W/3W) dBc/Hz**
-10000	-145.0 §	-142.6
-5000		n/a
-500	-132	-122.6/-127.6
-250	-126.5	-122.6/-122.6
-100	-120.5	-116.6/-116.6
+100	-120.5	-116.6/-116.6
+250	-127	-122.6/-122.6
+500	-130	-122.6/-127.6
+5000		n/a
+10000	-145.0 §	-142.6
§ - Wideband noise measurement may be limited by phase noise of 1.6GHz signal generator used as local oscillator.		

Table 1 – WBN Noise of Closed Loop including RF5110G at 850MHz

4.1.2 Results at 800MHz

The following tests were undertaken after the 400MHz tests (see section 4.2) with the RF5110G restored to 800MHz operation.

The RF5110G was found to deliver in excess of +31dBm mean power with TETRA modulation.

At +30dBm the Adjacent channel power of –69dB to –70dB was regularly observed. When the PA was operating continuously for extended periods, at +30dBm mean power or more, the ACP was never worse than –67dB to -68dB.

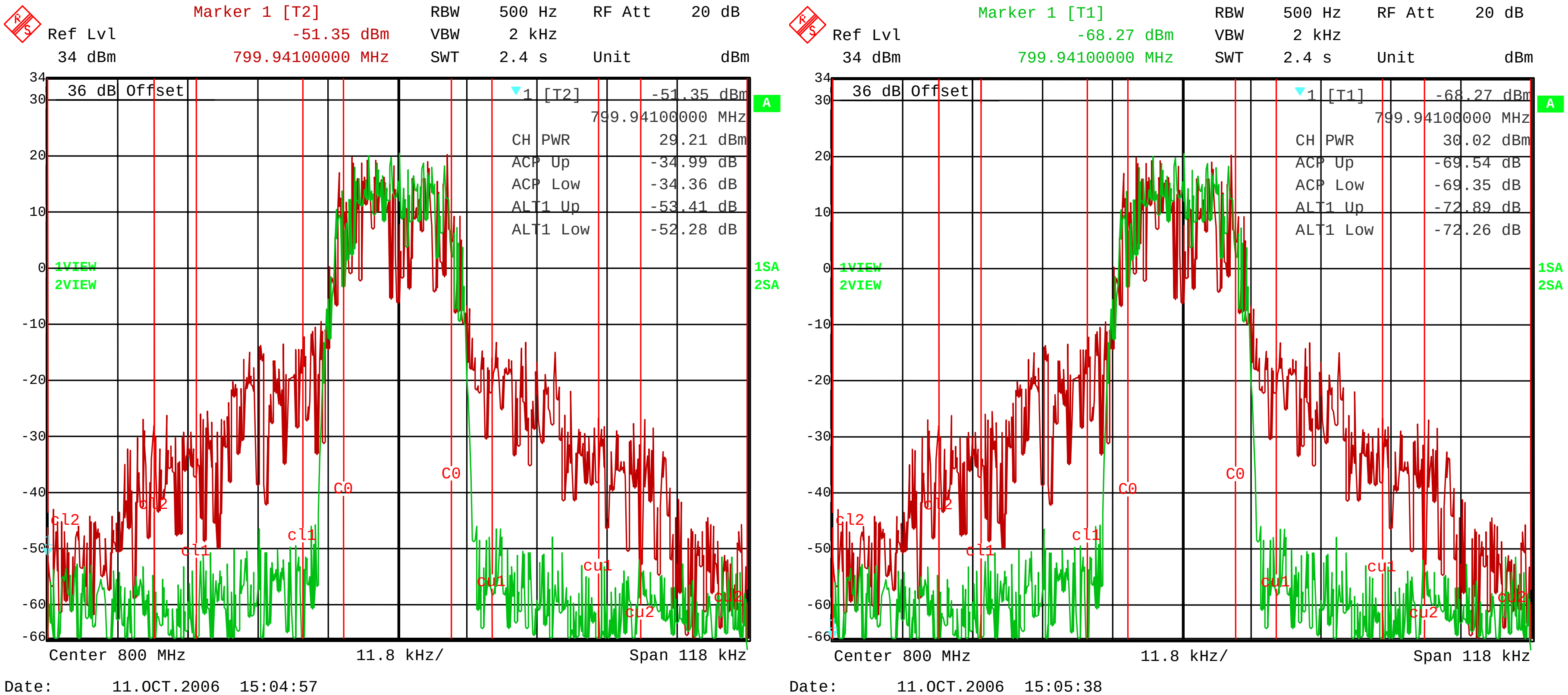


Figure 13 - Open and closed loop performance of CMX998 & RF5110G at 800MHz. The measurements listed in the upper right hand corner of the screenshots show performance of the open loop system (left) and closed loop (right)

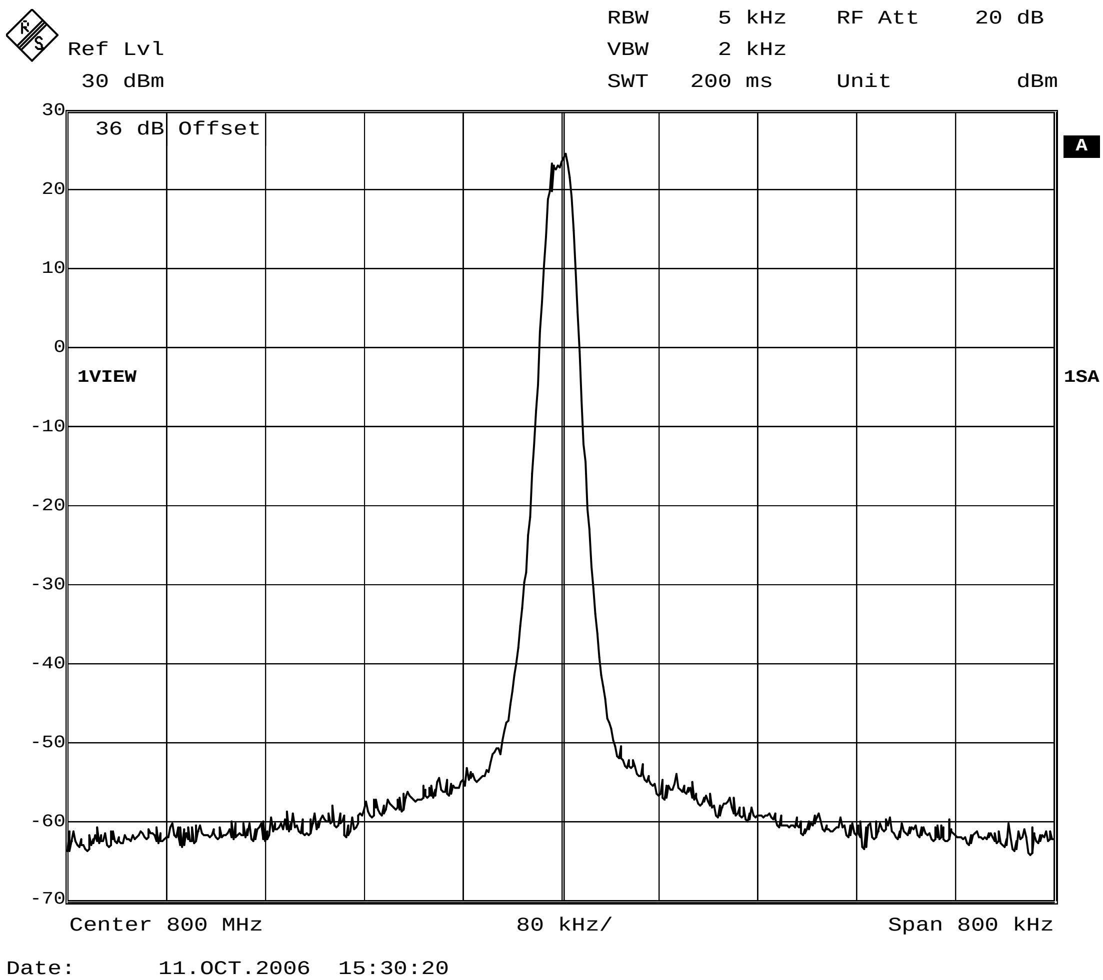


Figure 14 – Broadband spectrum produced by CMX998 with pi/4 DQPSK modulation, +30dBm mean power output

4.1.3 Operation with SMIQ

Some spurs were noted on the output spectrum with the CMX981 at +/-500kHz. Although the spurs were at a low level, the operation of the CMX998 / RF5110G was checked using a TETRA baseband I/Q source from an SMIQ signal generator. The result was a clean output spectrum as can be seen in Figure 15.

A measurement issue was observed during these tests. It was found that the spectrum analyzer was limiting the measurement of the 2nd adjacent channel. This is because the analyzer automatically switches into 'wide' PLL mode for ACP measurements. While this is optimal for the 1st adjacent channel, the 2nd adjacent channel performance is limited by the phase noise of the spectrum analyzer. The effect can be demonstrated by forcing the FSEA into 'narrow' PLL mode, the result is seen in Figure 17 and can be compared with 'wide' mode in Figure 16.

The calculated linearization improvement is:

	Adjacent (+/-25kHz)	Alternate (+/-50kHz)
Open Loop	-34dB	-53dB
Closed Loop	-68dB	-75dB
Linearization Improvement	34dB	22dB

Table 2 – Typical Linearization improvement of CMX998 with RF5110G at 800MHz

The EVM (Error Vector Magnitude) of the transmitter is shown in Figure 18. At around 3%, it is well within most system requirements.
(Note that no compensation correction or calibration is applied to achieve this figure).

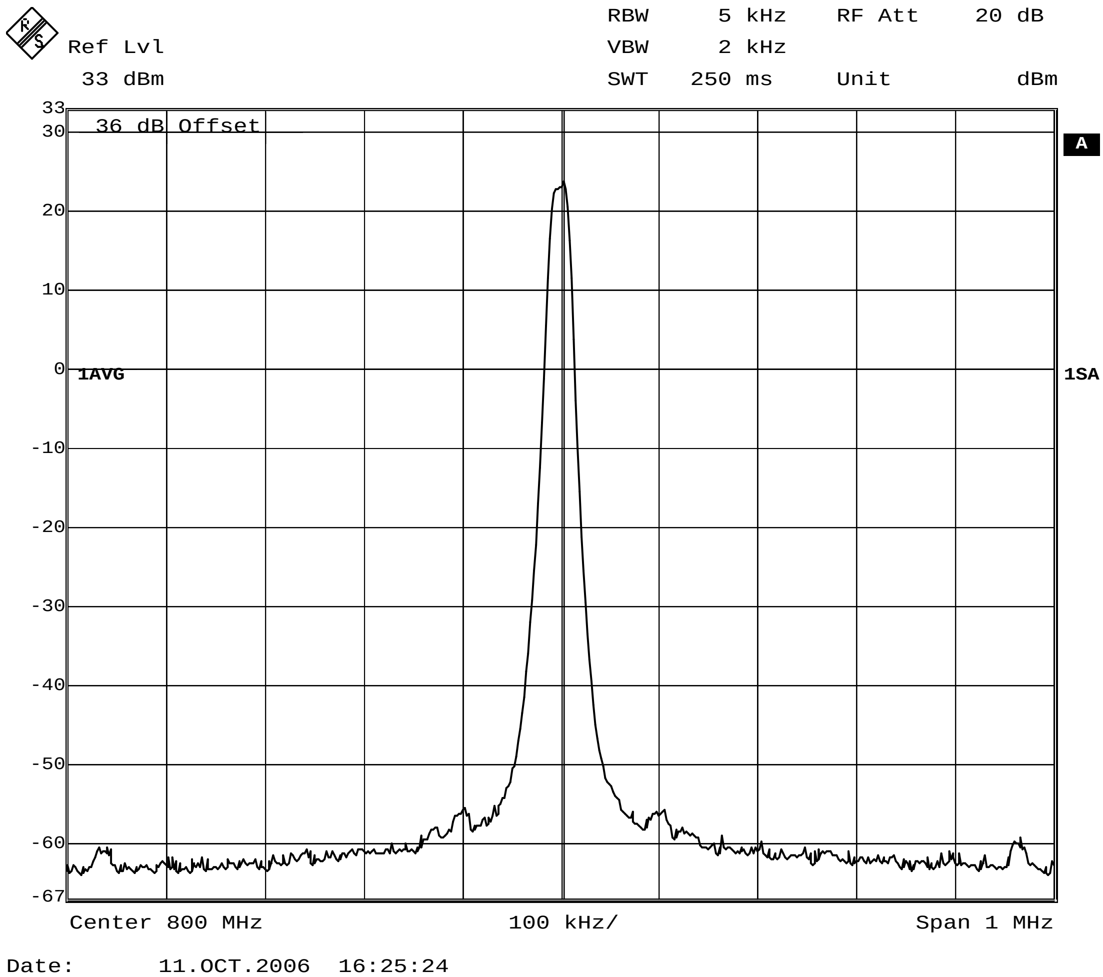


Figure 15 - CMX998/RF5110G output spectrum, closed loop, +30dBm output power with I/Q from SMIQ signal generator

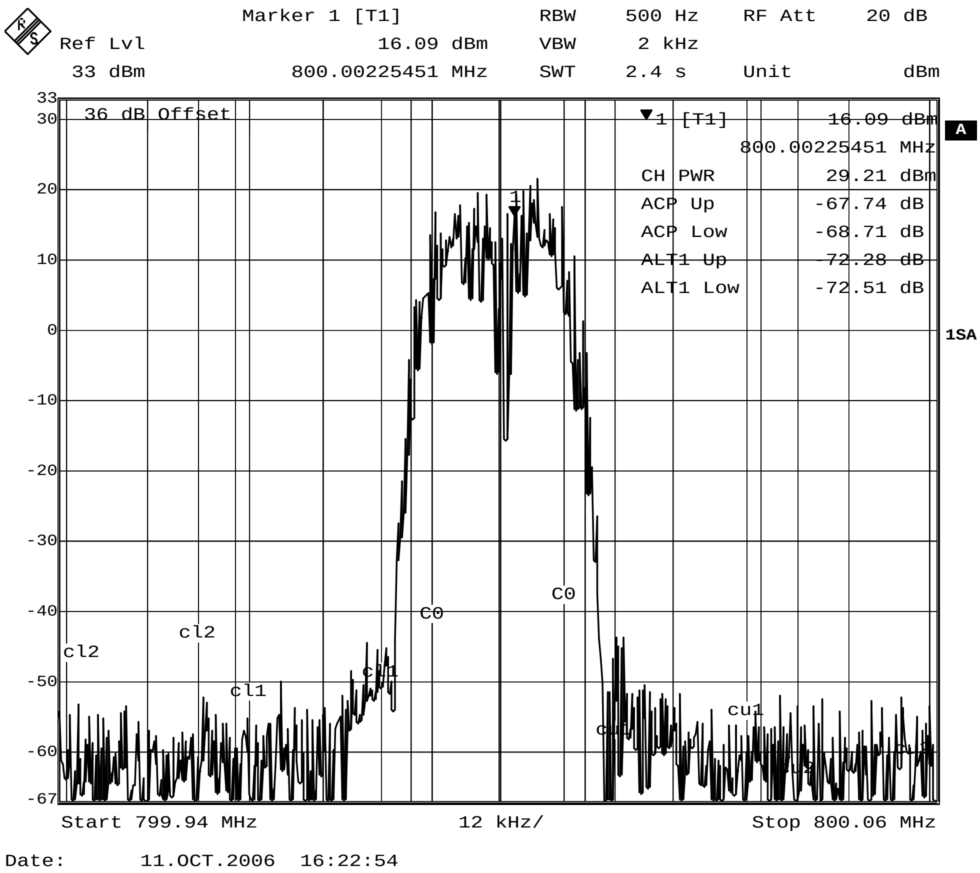


Figure 16 – Measurement with FSEA set to wide PLL

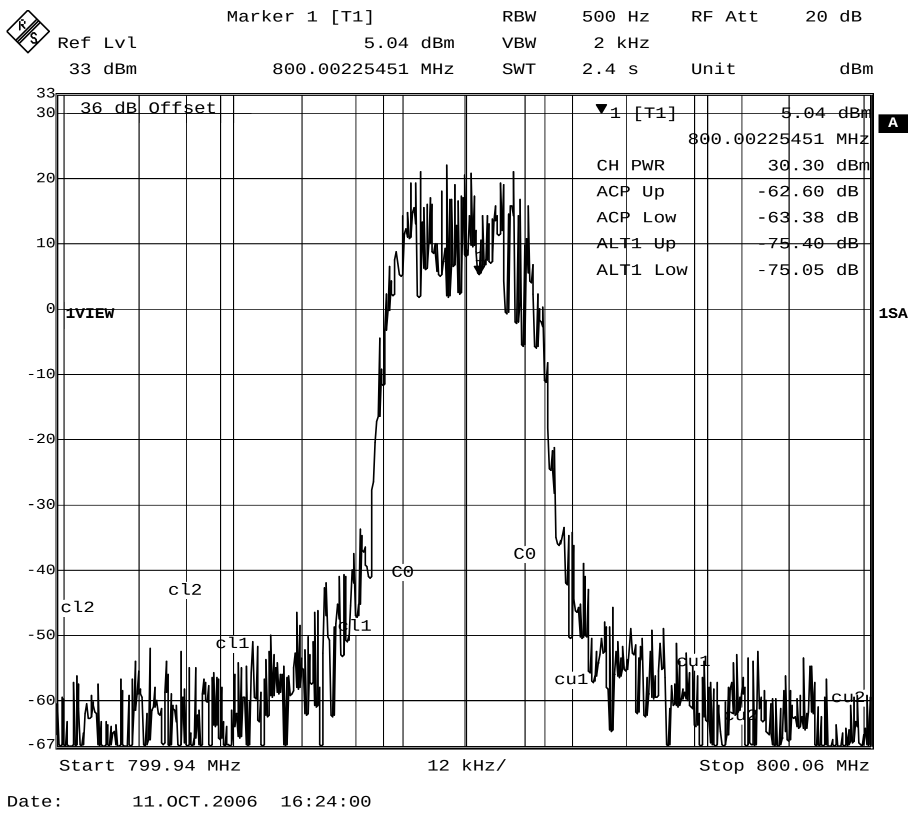
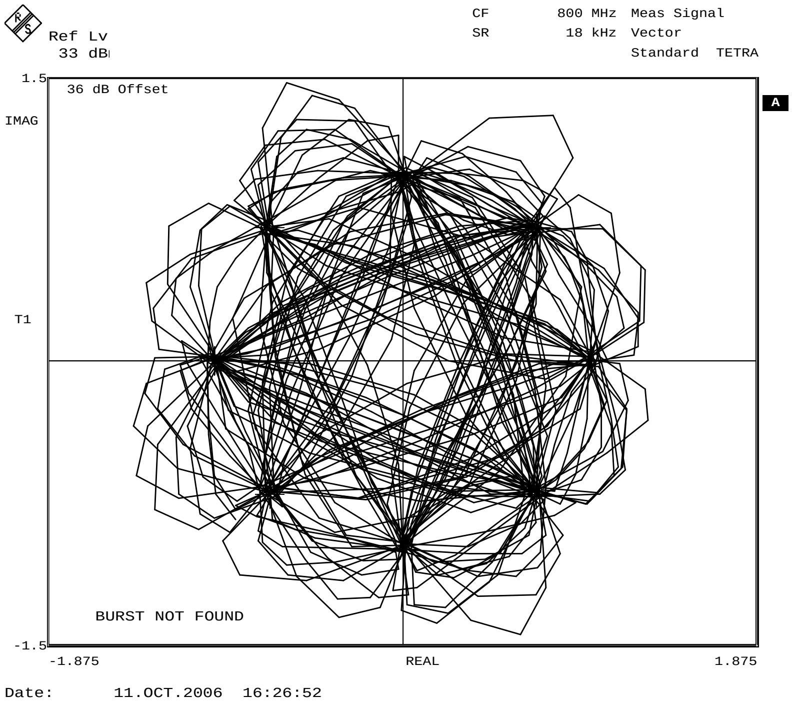


Figure 17 – Measurement with FSEA set to narrow PLL



Ref Lv
33 dB

Marker 1 [T1] 0 sym CF 800 MH
Value 2 SR 18 k Symbol/Erro
Standard TET

36 dB Offs — Symbol Table — A

0	10101001 10011101 11110101 01001100 00111111
40	10101000 10000001 11110011 00000100 00101010
80	00011000 11111100 01010010 00001001 11101100
120	00110100 01101000 10111001 01110011 10010111
160	00101001 01110010 11110111 00101110 00110010
200	11100100 10101110 01011011 11100101 11011000
240	01011100 11010001 11001010 11100100 10111110
280	01011011 10000101 11011001 00011100 11010110
320	01001010 11110101 10111110 00111101 10000100
360	10001101 00011011 00101110 01011010 11100101
400	11011110 01011100 11000101 11001010 10011100
440	10111111 01001011 10000011 10111001 00001001
480	10010110 0011

Error Summary — BURST NOT FOUND

Error Vector Mag	2.96 % rms	8.71 %	Pk at sym 5
Magnitude Error	2.10 % rms	5.64 %	Pk at sym 158
Phase Error	1.21 deg rms	4.40 deg	Pk at sym 44
Freq Error	-6.06 Hz	-6.40 Hz Pk	
Amplitude Droop	0.73 dB/sym	Rho Factor	0.9990
IQ Offset	1.18 %	IQ Imbalance	0.80 %

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Figure 18 - EVM with SMIQ signal source**.**

4.2 Operation at 400MHz

Using the modified RF5110G (see section 3.2), operation was tested at 390MHz and 400MHz. The RF5110G bias voltage was 2.8V and power supply was 3.5V. Results were extremely encouraging as can be seen from the excellent linearity in the following plots.

The adjacent channel power improvement is shown in Figure 19 and is summarized in Table **3**. The improvement in the alternate channel is probably limited somewhat by other factors rather than pure linearization gain available (see section 4.1.3).

	Adjacent (+/-25kHz)	Alternate (+/-50kHz)
Open Loop	-34dB	-55dB
Closed Loop	-68dB	-72dB
Linearization Improvement	34dB	17dB

Table 3 – Linearization improvement of CMX998 with RF5110G at 400MHz

Table **4** shows measurement results of the noise at offset frequencies and compares them to TETRA specification points. All noise measurements were done with a mean output power of +29.5dBm (+32.5dBm PEP).

Offset (kHz)	**Noise (dBc/Hz)**	**TETRA Requirements (1W/3W) dBc/Hz**
-5000	-147.5	-142.6
-500	-130.5	-122.6/-127.6
-250	-127.5	-122.6/-125.6
-100	-122	-117.6/-120.6
+100	-122	-117.6/-120.6
+250	-127.5	-122.6/-125.6
+500	-132	-122.6/-127.6
+5000		-142.6

Table 4 – WBN Noise of Closed Loop including RF5110G @385MHz

Modulation accuracy requirements are well within TETRA specifications (Figure 20). Please note that these results are not compensated for I/Q imbalance in the CMX998 feedback path. The inherent EVM in the CMX981 modulation[2] is also a significant factor in the EVM measurement.

[2] TETRA pi/4 DQPSK modulation filtering is optimized for a combination of good adjacent channel power and EVM. Choices that were made to achieve good ACP increased EVM in the modulation.

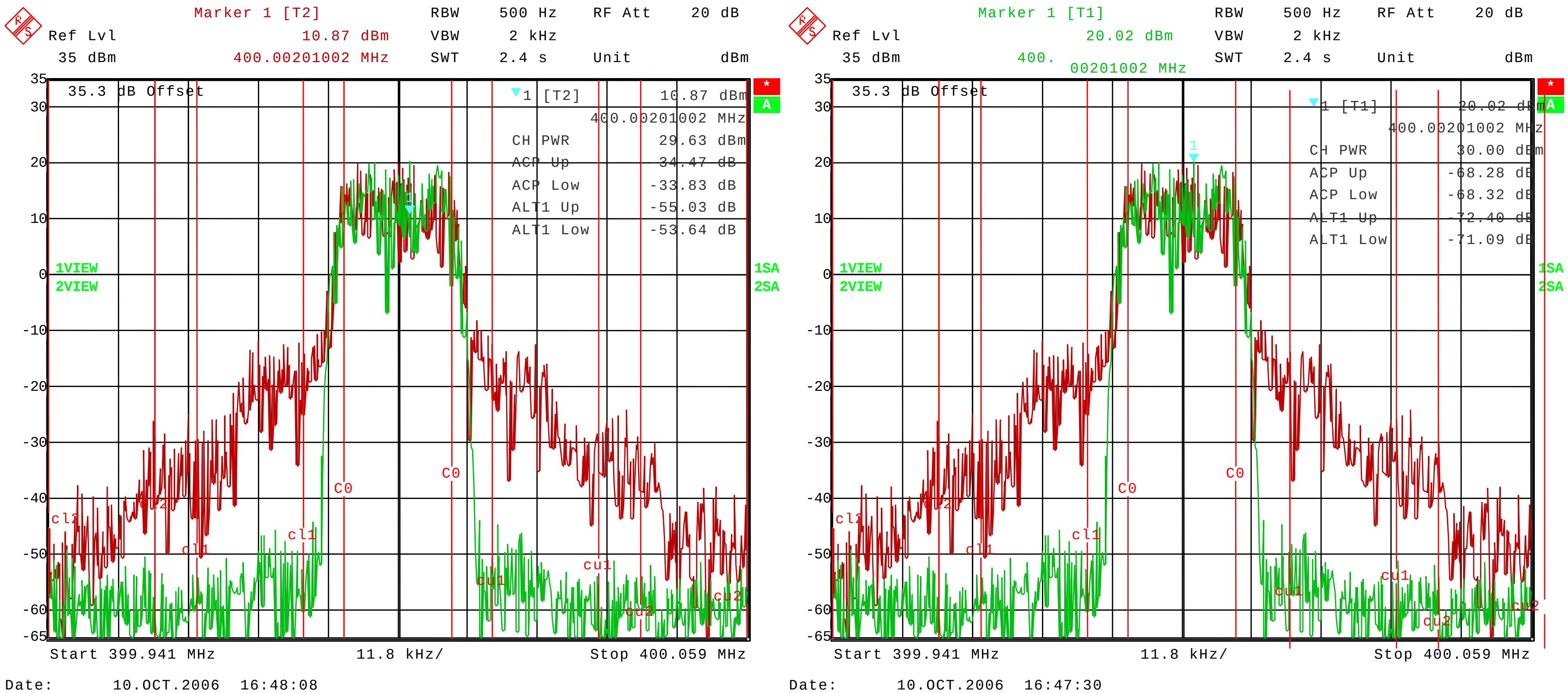

Figure 19 - Open and closed loop performance of CMX998 & RF5110G at 400MHz. The measurements listed in the upper right hand corner of the screenshots show performance of the open loop system (left) and closed loop (right).

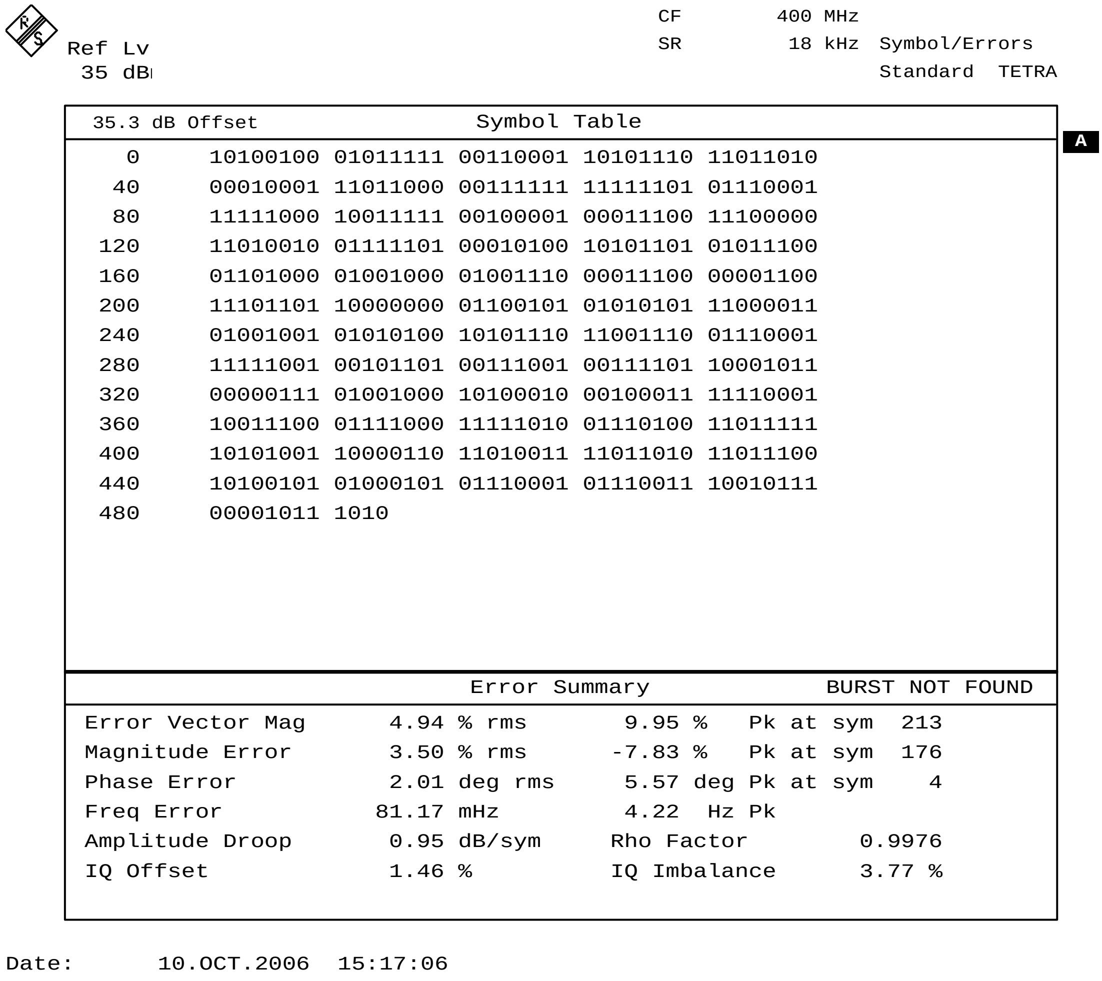

Figure 20 - Modulation performance of CMX981 / CMX998 / RF5110G at 400MHz

5 Conclusions

The CMX981/CMX998/RF5110G combination has been found to perform very well at both 400MHz and 800-850 MHz. TETRA requirements for a 1W transmitter are easily achieved.
Modulation linearity is very good and wideband noise is typical of CMX998 performance.

The RF5110G appears to be a good choice of a RoHS compliant power amplifier module to use with the CMX998. It serves applications around the 1W power level over a broad range of frequencies.

6 References

[1] CMX998 Cartesian Feed-back Loop Transmitter datasheet, Ver. 5, November 2006
[2] CMX981 Advanced Digital Radio Baseband Processor datasheet, Ver. 1, September 2002
[3] ETSI EN 300 392-2 Terrestrial Trunked Radio (TETRA) voice and data. Part 2: Air Interface V2.4.2 (2004-02)
[4] RF5110G datasheet see www.rfmd.com

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