A New Generation Cartesian Loop Transmitter for Flexible Radio Solutions and Software Defined Radio

Authors: C.N. Wilson and J.M. Gibbins

Introduction

A key problem facing ‘Software Defined Radio’ (SDR) designers occurs if the system must support linear modulations schemes, i.e. modulations that have significant amplitude content. Such modulations present a challenge as either the Power Amplifier (PA) must be inherently very linear, which generally involves a very high power consumption; or some form of linearization scheme needs to be used.

The situation is complicated by another requirement often found in modern radio designs – to re-use a solution across a range of designs. This means one solution often has to meet the requirements of hand-portables, mobiles and in some case fixed stations. Further, in markets like specialised / professional radio systems or military systems a product can span operating frequencies from 150MHz to 1GHz.

Various linearization schemes come to mind to meet this requirement but the focus of this article is Cartesian feedback. It will be seen that with a modern integrated solution this scheme can offer a genuine answer to all the challenges discussed above.

The Cartesian Loop

The Cartesian Feed-back Loop (CFBL), first developed in the 1980’s [1,2], is now well established as a solution for highly efficient linear transmitters using modulation such as p/4-DQPSK, 8PSK, QAM etc. The scheme has been universally utilised in products implementing the TETRA standard [3] and also widely used in Japanese digital technology. The Cartesian Loop has the advantage of offering a large degree of linearization improvement; gains of over 30dB are not untypical. It is most suited to channel spacing up to about 200kHz; beyond this keeping the loop stable becomes a compromise with linearity improvement.

Integrated solutions have been in use for a number of years but the requirements of low noise and high linearity offer a number of challenges to IC designers. Now, with modern IC processes, solutions offer performance and functionality that makes the adoption of the technique over more product areas increasingly attractive, opening the door for SDR transmitters.

The Cartesian Loop works to improve the linearity of a power amplifier device by the action of negative feedback. A block diagram of the scheme is shown in Figure 1. The input signal is required in in-phase and quadrature (I/Q) format. This is applied to a summing amplifier (usually known as the ‘error amplifier’) where it is compared to the feedback signal. The output of the ‘error amplifier’ is applied to an up-converter to generate an RF signal that is then amplified by a PA. A sample of PA output is then down-converted and applied to the error amplifier. This closed loop system will attempt to correct the signal at the PA output to match the I/Q input signal applied to the error amplifier.

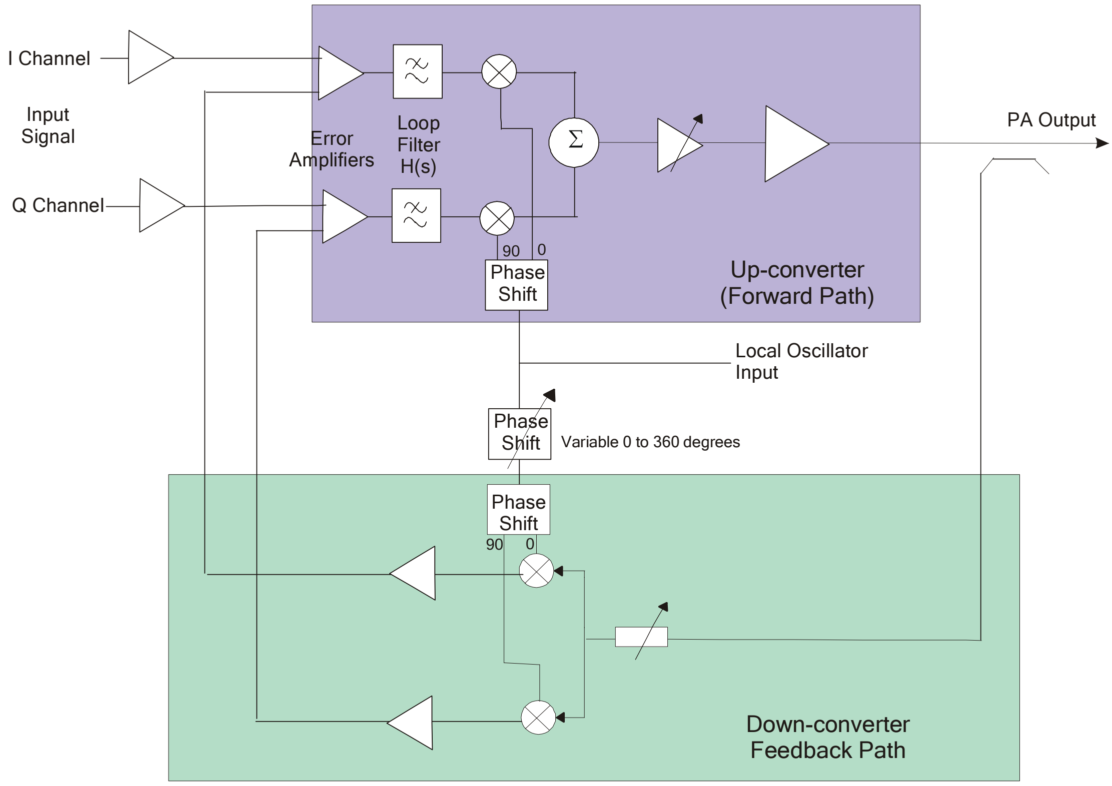

Figure 1 – Cartesian Loop

The effectiveness of the solution is demonstrated in the results shown in Figure 2 where the upper trace is the PA operated without the feedback and the lower trace is with feedback applied; in both cases the output power is approximately the same. It is obvious that the closed loop spectrum is a substantial improvement on the un-corrected performance of the PA.

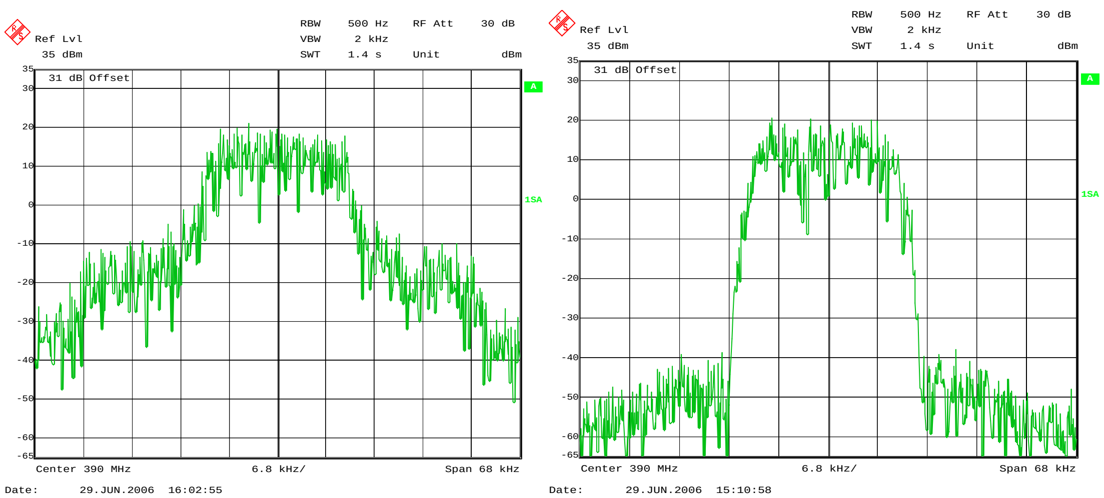

Figure 2 – Cartesian Loop Linearization using the CMX998, open loop (left) and closed loop (right) with p/4-DQPSK Modulation, 390MHz and 1W output.

To achieve these results it is necessary to ensure that the feedback phase is correct; this can be done by including a variable phase shifter in the LO path. Also it is necessary to include a means of constraining the loop bandwidth to ensure stability, hence a filter is included either around the ‘error-amplifier’ or immediately after it.

The Challenge

The need to avoid introducing distortion in the feedback path places demanding requirements on the design in terms of linearity and noise. The need for low wide-band noise also makes the design of the up-converter challenging. Further the need for excellent isolation between up-converter and down-converter (as well as baseband I and Q signals) makes the Cartesian Loop a challenge for IC designers.

Traditional markets using CFBL solutions have been 25kHz-channelled radios at 300-500MHz. For some time manufacturers have been demanding solutions operating up to 1GHz while running from 3V, taking less current than before and with no compromise in performance.

To examine what can be achieved with a modern CFBL design, we will use the CMX998 IC (ref [4]) as an example. The CMX998 represents a state of the art solution for a flexible integrated CFBL design.

Typical Performance

The TETRA standard is a good benchmark for CFBL transmitters because it requires good linearity (–60dBc adjacent channel power) as demonstrated in Figure 3.

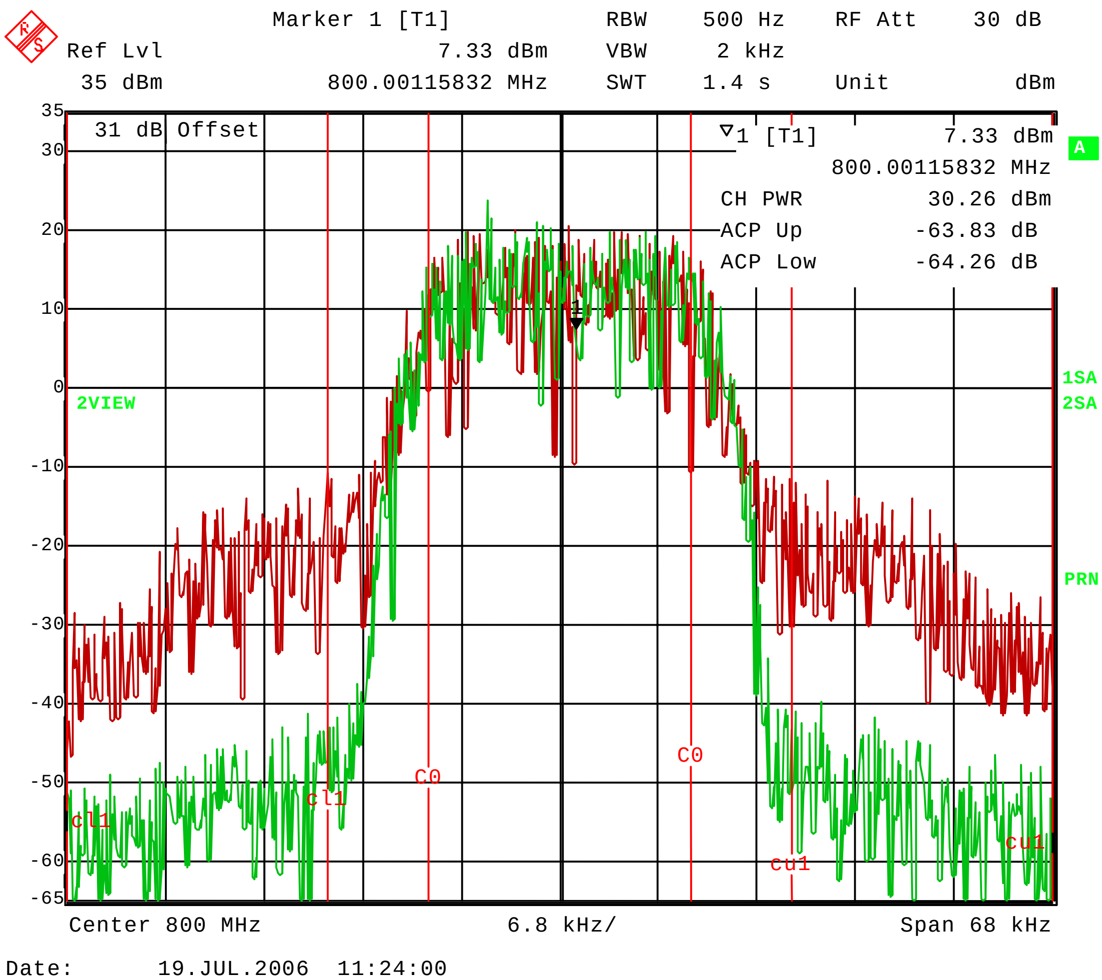

Figure 3 – Cartesian Loop Linearization using the CMX998, open loop (red) and closed loop (green) with TETRA p/4-DQPSK modulation, 800MHz and 1W mean output.

Wideband Noise

A key performance requirement for some PMR standards is low wideband noise. The Cartesian Loop is like any closed loop system in that noise inside the loop bandwidth behaves differently than noise outside the loop. Wideband noise, for example at a 5MHz offset, is typically outside the loop bandwidth and is generally dominated by noise from the up-converter section. Closer to the carrier, e.g. at 100kHz offset, noise is generated within the loop bandwidth and this is often dominated by the noise figure of the down-converter. The effect can be seen in Figure 4 where noise is relatively flat to about 500kHz then rolls off quickly as the edge of the loop bandwidth is reached. Also shown on the graph are the TETRA 1W and 3W requirements and it will be observed that the CMX998 based solution easily meets these.

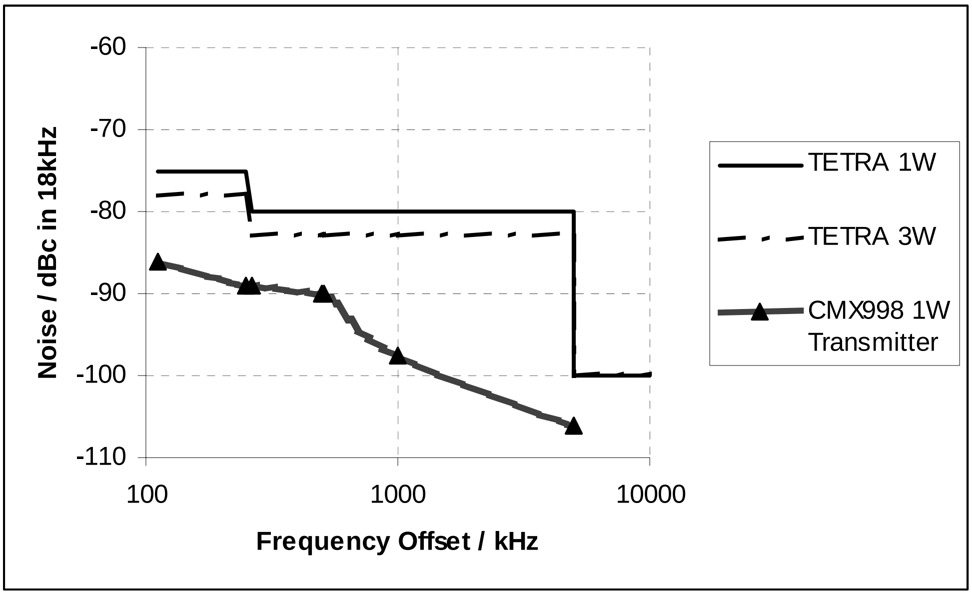

Figure 4 – Wideband Noise Performance of 1W (mean power) Transmitter using CMX998

Versatility

Today manufacturers are looking for versatile IC’s so a common design can be used in multiple products. An example of the versatility of the CMX998 CFBL solution is shown in Figure 5 where operation is at 150MHz and the output power is 10W mean, 20W peak. The PA used was a Toshiba S AV35, 32W, VHF marine band PA module designed for FM (constant envelope, not linear) operation but the CMX998 has no problem producing a clean, linearized transmit spectrum as can be seen in the lower trace on the plot.

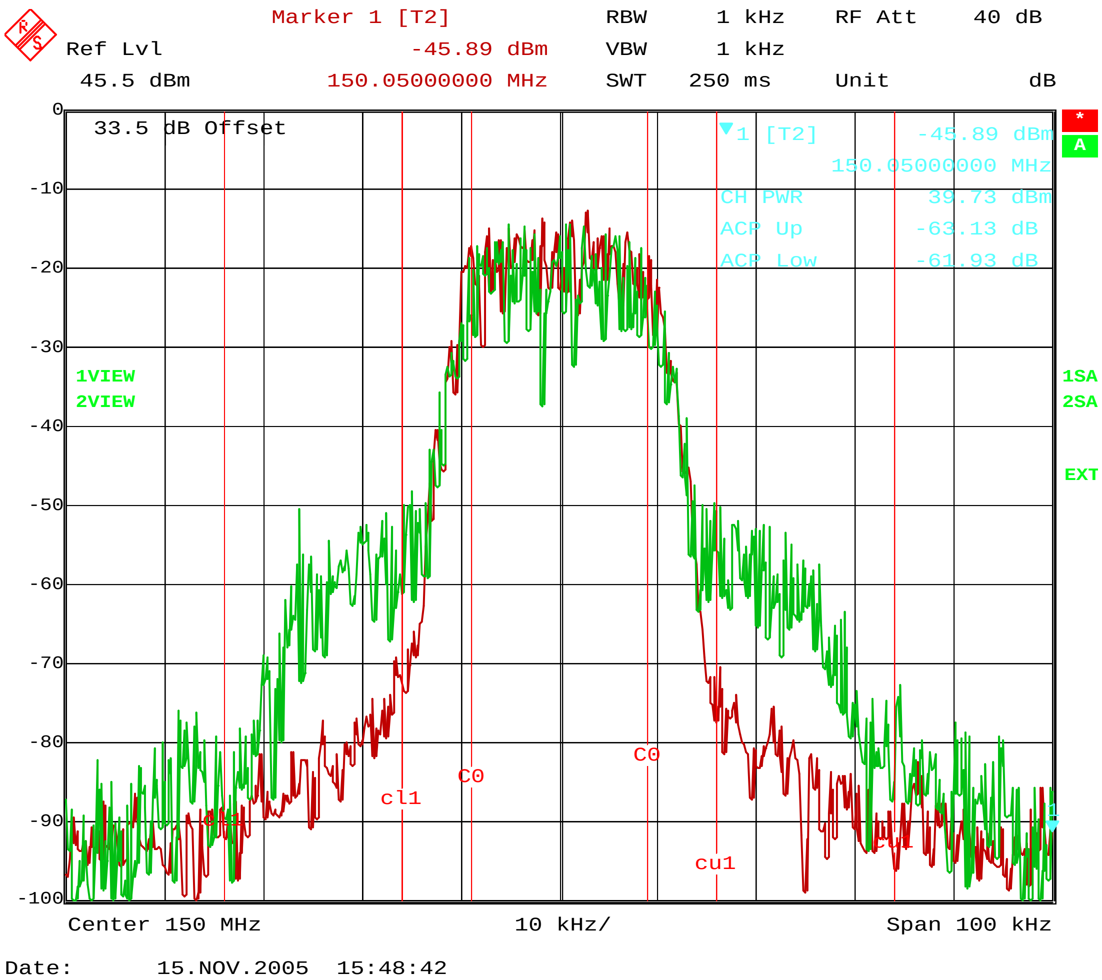

Figure 5 – CMX998 and S-AV35 operation at 10W (mean power), upper trace is open loop, lower trace is closed loop, p/4-DQPSK modulation.

Because it is an analogue system the loop will reproduce whatever modulation is placed on the I/Q inputs, be that QPSK, GMSK, QAM, Analogue FM, OFDM, etc.

A tough test of the flexibility of a linearization system is a two-tone test. Although the PAPR (peak to average power ratio) of a two-tone signal is only 3dB the fact the modulation has a zero (effectively goes through the origin in I/Q format) makes it a challenge for some linearization schemes, such as Polar Loop. As can be seen in Figure 6 the Cartesian Loop deals with two-tone modulation very effectively.

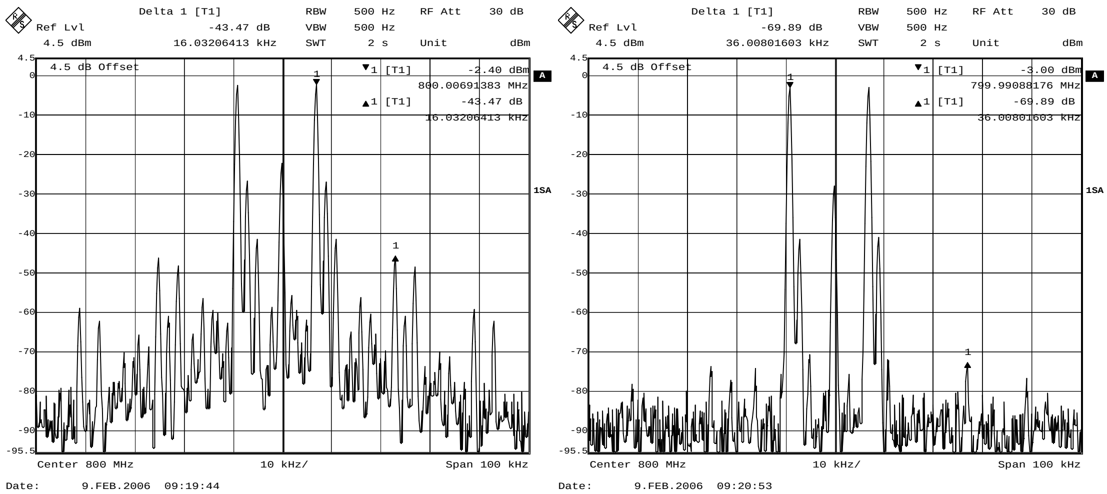

Figure 6 – Cartesian Loop Linearization using the CMX998, open loop (left) and closed loop (right) with two-tone modulation, 800MHz.

Future Technology – Broadband / Multicarrier / QAM

With the move to higher user data requirements there is a general move to higher on-air bit rates, which often this means broader bandwidth and higher-level modulations.

To test performance for higher bit rate systems evaluation has been carried out using 16 QAM, RRC filtered with roll off factor = 0.2, 115.2ksym/sec (460.8kbps) modulation in a 150kHz channel. The modulation’s peak-to-average power ratio was approximately 8dB. The loop configuration, eye diagram, and linearized spectrum results for this 150kHz wideband modulation are shown in Figure 7, Figure 8 and Figure 9.

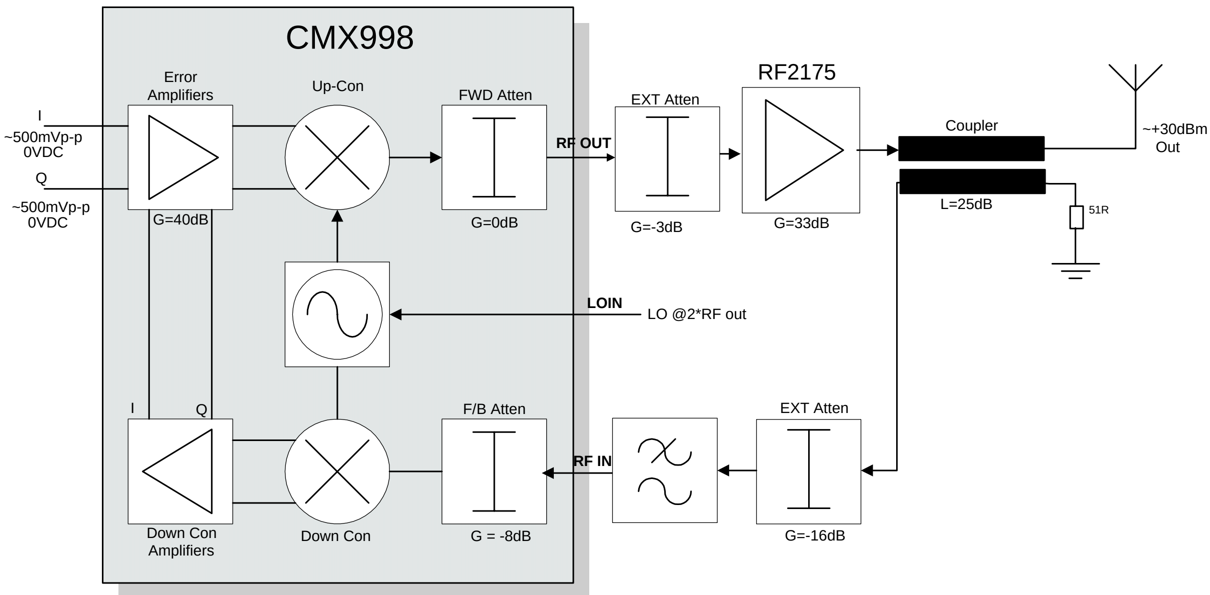

Figure 7 – Loop Configuration for 150kHz wideband testing

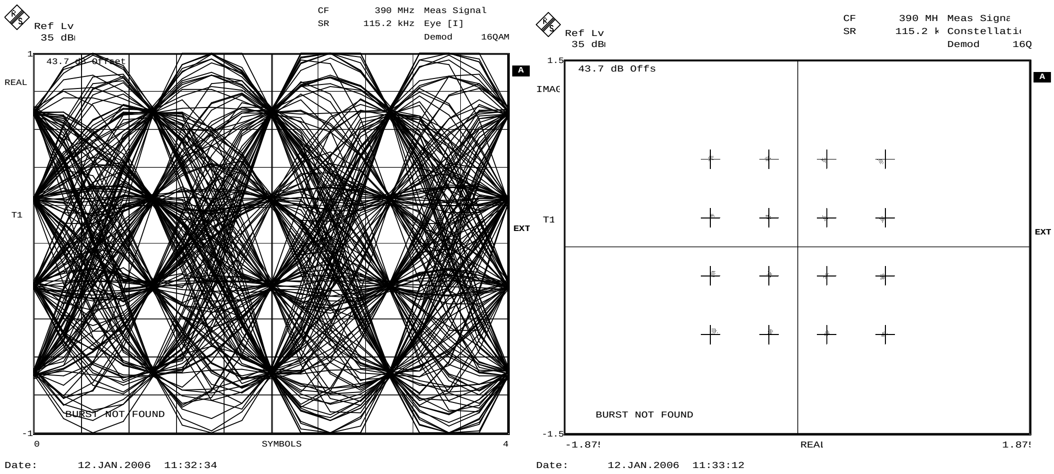

Figure 8 – 150kHz QAM Eye & Constellation Diagrams

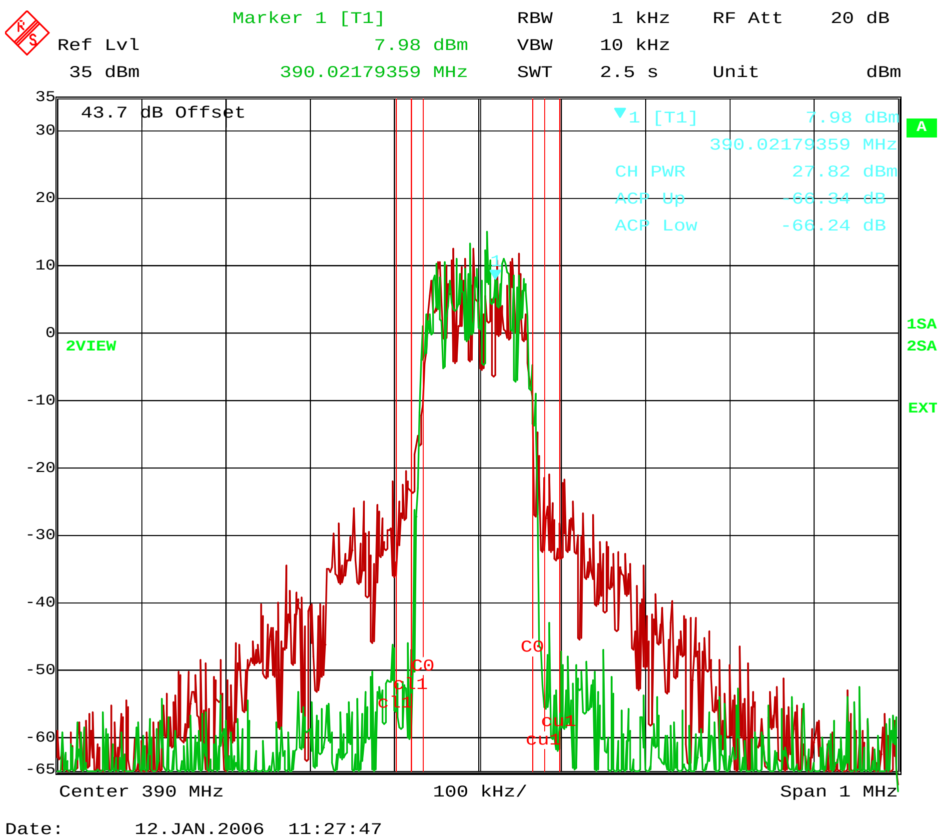

Figure 9 - 150kHz QAM Open (upper) and Closed (lower) Loop Modulation on 1MHz Span

The results show the CMX998 can linearize systems with 150kHz bandwidth signals very well; approximately 25dB linearization can be observed.

One of the main alternatives to the Cartesian scheme is ‘Polar Loop’ however it is not as straightforward to implement as it appears; typical Polar Loop linearization gains are relativity small perhaps only 6dB to 10dB compared with the 25dB at 100kHz offset as demonstrated by CFBL in Figure 9.

Conclusion

We have seen that the CMX998 demonstrates a practical solution that fulfils all the key requirements of a SDR transmitter. Multiple modulation formats, excellent modulation accuracy and flexible configuration are all achieved.

In addition to the benefits that have already been discussed further benefits include:

- Low spurious emissions
    - No high frequency clocks
    - No DAC spurs cf. Direct Digital Synthesis (DDS)
- Low broadband noise (compared to DDS)
- Simple DAC requirements
    - Two DAC’s operating at the modulation rate
- High level of integration

References

[1] Petrovic, V., "Reduction of Spurious Emissions from Radio Transmitters by means of Modulation Feedback", IEE Conference on Radio Spectrum Conservation Techniques, 1983.
[2] Petrovic, V., "VHF SSB Transmitter Employing Cartesian Feedback", IEE Conference on Telecommunications, Radio and Information Technology, 1984.
[3] ETSI EN 300 392-2 Terrestrial Trunked Radio(TETRA) voice and data. Part 2: Air Interface V2.4.2 (2004-02)
[4] CMX998 Datatsheet, available from www.cmlmicro.com
[5] CMX981 Datasheet, available from www.cmlmicro.com