# Four years of measuring digitally modulated RF signals. What have we learned?

Chris Swires. Swires Research.

The first paper I presented on measuring digital signals was to the SCTE in September 1997. Another paper entitled “Are all your bits in place” was presented as a SCTE lecture the CAI conference in 1999. Two years on I though it appropriate to review the current situation.

During the last few years a great deal of *real world* experience has been acquired as cable, terrestrial and satellite digital services have been deployed. Many practicalities have now emerged.

First I will very briefly, try to bring you up to speed on the conclusions made 2 years ago.

The question of the relevance of the bandwidth of the measuring instrument was discussed at length and I believe that it is now well known and understood that digital signals levels must be measured at the correct bandwidth.

The use of a spectrum analyser has been confirmed as very valuable in ensuring that the digital signal does not suffer from slope or response problems.

As predicted the change from perfect picture to break-up is sudden and catastrophic, no more graceful degradation from slight noise to severe noise.

The methods of monitoring system performance discussed in my first paper four years ago were bit error rate monitoring (BER) and signal to noise measurement.

I concluded that my preferred measurement was signal to noise as BER monitoring only showed errors when the system was within 4dB of failure. Signal to noise measurements could readily be made showing margins of over 10 dB before system failure. The added advantage of measuring signal to noise is that this measurement can be made on a low cost instrument, as it is not necessary to demodulate the signal.

Two years later In my 1999 lecture I discussed the use of constellation diagrams and the measurement derived from them, MER (modulation error ratio) and predicted that these measurements would be found increasingly valuable.

Fortunately I do not wish to change any of these conclusions but all measurement methods have limitations and it is these limitation I would like to discuss in this paper.

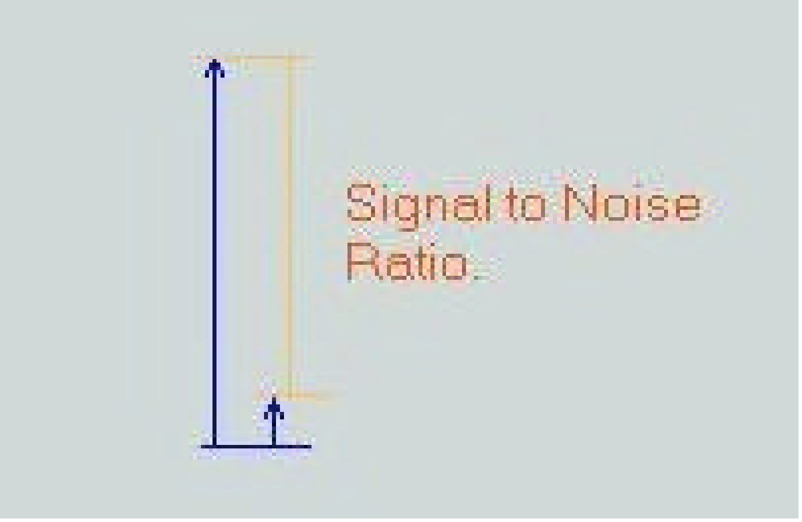
Measuring in the real world.

Here is our ideal instrument. Wristwatch size. Battery life 10 years before recharge. Head-up technology gives a full colour virtual image. Measures MER; constellation diagrams full colour demodulated decoded picture cost £100.
Delivery 8 years.

**Available now** low cost instruments about £200-£300, these measure signal level and signal to noise ratio. Easy to use every technician should have one.

**Available now** instruments to measure constellation diagrams, MER BER cost greater that £2000, valuable in the hands of **trained** technicians.

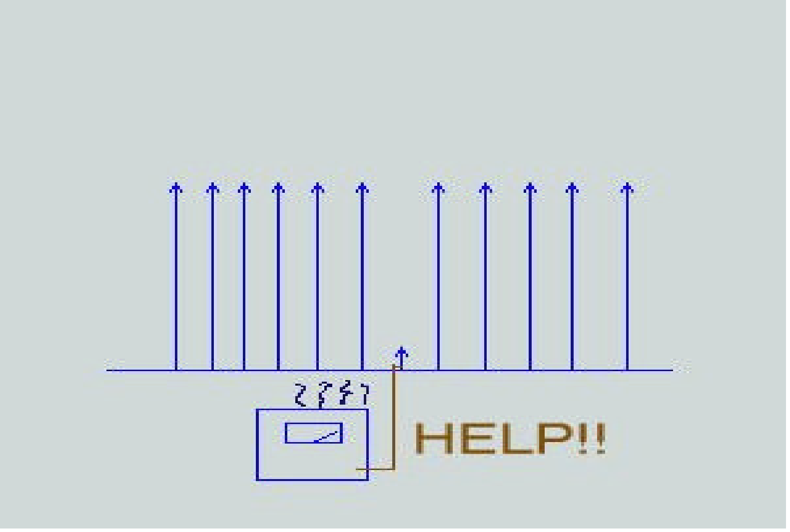
**Signal to noise measurement**



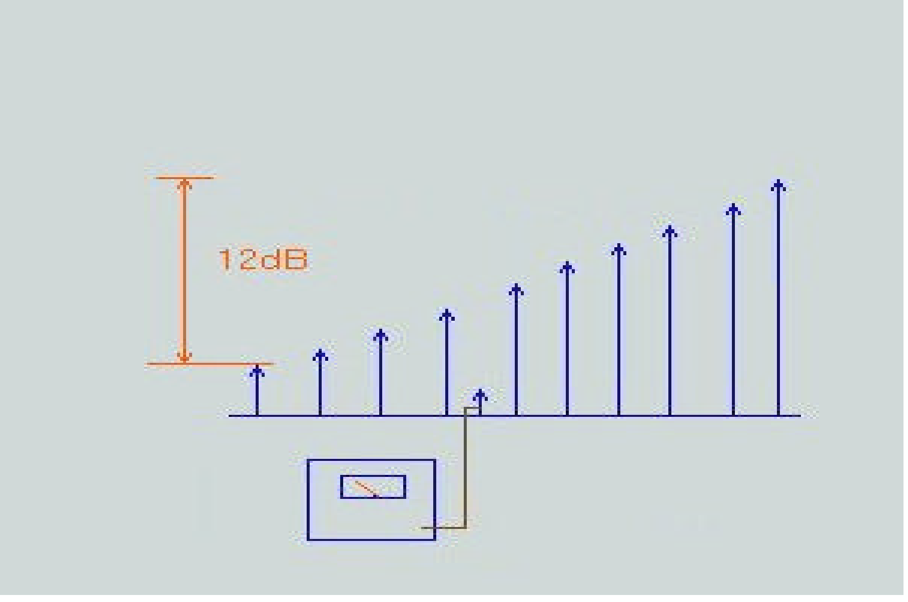
Nice and simple, measure the level of the desired signal, then move to a frequency away from the signal and measure the level of the noise floor. The difference in dB's is the signal to noise ratio.

In the real world this apparently simple measurement can cause a great deal of argument and trouble.

The problem is not in the measurement but in the environment in which the measurement is made.




The noise floor measurement made by the test instrument is in the presence of many signals often with peak amplitude 60 dB greater than the signal to be measured. These high levels can cause overloading of the signal level meter or spectrum analyser used to make the signal to noise measurement. The noise floor may contain beat products from analogue vision carriers that are higher than the noise level.



Both the above problems can be made worse where a very high pre-correction slope is used .For example where Bridger amplifiers are launching into long distribution lines. Where 12dB of slope between 50 and 750 MHz is used measurements made at 50 MHz have the additional loading of the higher frequency, higher amplitude carriers at the upper end of the band. With a spectrum analyser which has a broadband input this level is imposed directly on the input amplifier and mixer. In addition the triple beats from the cable system that that fall into the low frequency part of the band are effectively made 12dB worse by the use of slope in the network. Conversely at the end of long distribution lines there will be higher levels at the lower frequency end of the band giving the same problems when attempts are made to measure at 750MHz.

This is a difficult problem for the test equipment manufacturer. The RF input stage and the input mixer must be designed with a very high dynamic range to successfully measure a low level noise floor in the presence of high level carriers. We have spent a great deal of time developing suitable input circuits and I am sure that other manufacturers have done the same.

Even with good design the margins available to the test equipment manufacturer are small and the following points will help to ensure that the network is being measured and not the noise floor or the overload characteristics of the test equipment.

For the network operator it is important to pick suitable test frequencies. Placing the reference channel and the noise floor reference frequency as close together as possible reduces the effect of errors due to slope on the network.

Use a spectrum analyser preceded by a high Q band-pass filter to find a clean area in the noise floor. The filter should eliminate any overload effects within the analyser but reveal any residual noise and intermod products from the cable network.. Remove the filter and measure the level of an adjacent carrier. The signal to noise ratio is then computed by subtracting the level of the noise floor from the carrier level (both readings to be made with the same bandwidth setting on the analyser) This reading represents the best possible result at this point on the network.

The best point to make a system noise measurement is at the output of a Bridger amplifier, here the signal is very high and the signal to noise ratio is at it’s best.

The test equipment to be used should then be tried in place of the spectrum analyser and high Q band-pass filter. The test equipment being checked should give the same reading as the analyser and filter, (within the sum of the specified tolerances of the two instruments).

Working at lower levels on the system poses extra problems because as the level is lowered the noise floor of the instrument is approached.

Assuming that the meter scales are accurate and the meter is well designed the problems outlined above will only degrade measurements. Overload of the instrument, intermod products ingress or noise within the instrument will make the signal to noise reading worse than it is. These measurements are unlikely to give an optimistic signal to noise ratio!

We have thousands of simple digital instruments in service. Where we have investigated problems of low signal to noise readings they have been resolved by carefully finding suitable measurement frequencies.

**MER measurements.**

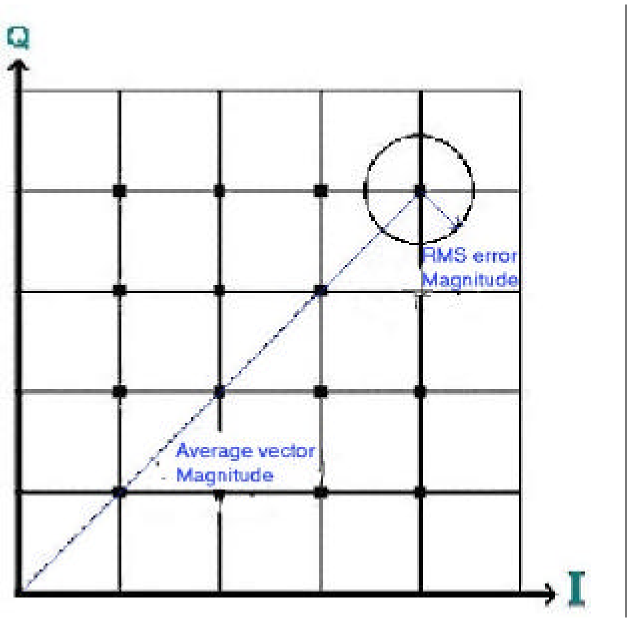
Is there a better way of measuring signal to noise ratio? Yes, it comes under the name MER.

**MER can be regarded as a form of signal to noise ratio measurement that will give an accurate indication of a receiver's ability to demodulate the signal, because it includes not just Gaussian noise but all other uncorrectable impairments of the received constellation as well**

**If the only significant impairment present in the signal is Gaussian noise then MER and Signal to noise ratio are equivalent.**

MER is derived from the demodulated signal which can be displayed as a constellation diagram Because MER is an in channel measurement many of the problems associated with signal to noise measurements are eliminated. MER gives the noise within the channel under test and does not rely on relating to a known noise floor in the system. Any channel can be measured at any frequency.

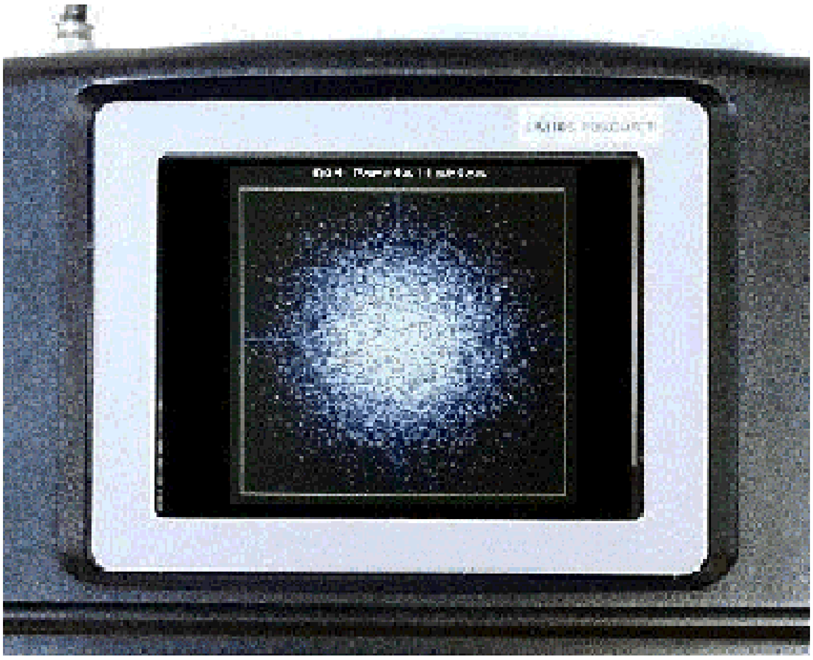
In a constellation diagram, each point represents the gain and phase of one bit. Should a point stray into the area occupied by another point a bit error will occur.



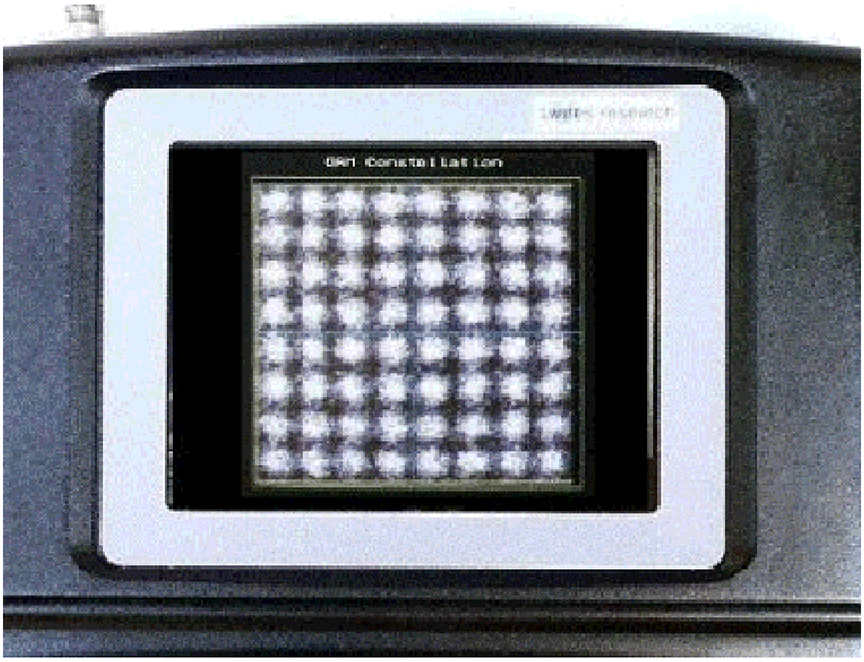

The above diagram shows one quarter or quadrant of a constellation display of a 64 QAM signal, from the following formulae MER can be calculated.

MER(dB) = 20 log (RMS error magnitude/ average signal magnitude)

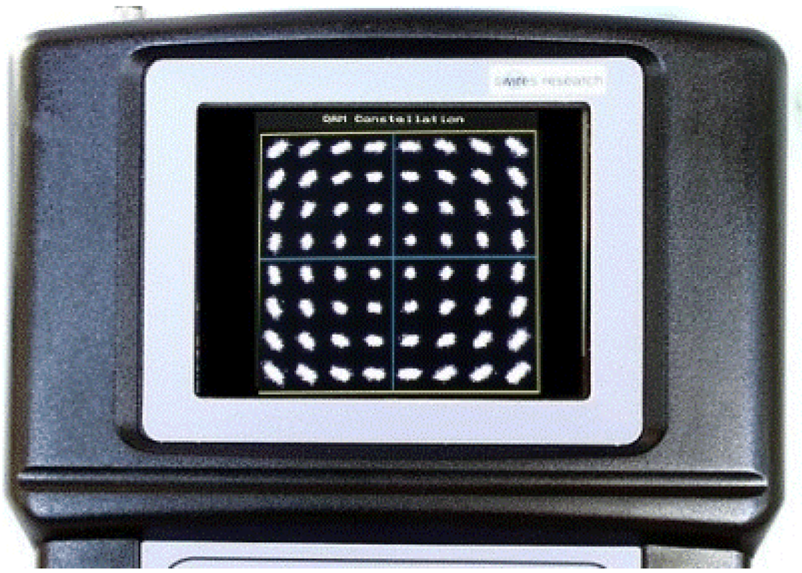

Shown above is a constellation display with a MER of about 32 dB



The signal has not locked. If you see this you have problems!



A very bad MER, this is locked and would give a perfect picture  but with no noise margin .




The picture above shows the effect of phase noise as the rounding effect this is most noticeable at the corners of the display.


This ‘polo mint effect is caused by a single carrier interference, in channel approximately 25 dB down on the digital signal.

The accurate measurement of MER does demand a very high quality RF unit and demodulator. With a piece of test equipment the instrument must have a sufficient margin to measure performance that is better than any active part of the system, if meaningful results are to be obtained. In a set top box a performance good enough to produce a picture is the only requirement.

At the present time UK cable companies are using 64 QAM but tests have been carried out using 256 QAM. 256 QAM needs a signal to noise or MER performance some 5-6 dB better than 64 QAM

Typical headend modulators that we have measured give between 37 and 40 dB MER.

256 QAM. Once again the management prepares to throw away the valuable resource called performance margin!

Lowest MER to lock set top box 28 dB
Add 6dB margin = 34dB MER.

This comes very close to the 35 dB measurement limit for most current test instruments.

As soon as it became likely that 256 QAM would be deployed we began a programme to improve the performance of our instruments.

The work we carried out resulted in improved performance from our instruments and has achieved a typical MER limit of 40dB.

An analyser or meter for measuring MER has to operate with an 8MHz bandwidth.

Taking the fundamental noise limit from the well known formula

E = Square root of 4KTBR

Where E= EMF in volts
K= Boltzmanns constant (1.38 * E-23)
T = temp in degrees Kelvin
B == bandwidth in Hertz
R= resistance in ohms.

Gives E=  3.115 u.V.(for an 8MHz channel)

Normalising to one milivolt and converting to dB gives –56 dBmv.

The signal to noise of a stage is  = Noise in a perfect load at 1mV + input level in dB mV – noise figure of the stage in dB.

For a signal to noise ratio of 40 dB given a realistic 8dB noise figure

Input level = 8 + 40 –56 = -8dBmV.

So to measure a BER of 40 dB we have (assuming no other degradation in the unit) a need for a minimum input level of –8dB mV.

Currently a minimum digital level of –12 dB for 64 QAM signals is typical which gives a very best **Theoretical MER of 36 dB assuming no degradation anywhere in the network!**

We need 34 dB MER to run 256 QAM so levels will have to be increased, taking us nearer to overload in the amplifiers etc.

The limbo dancer sums up the problem! Lower headroom , higher noise floor!

Having developed an instrument with a very low noise figure and a very high overload characteristic we looked to see what other factors degrade the MER performance of an instrument.

A major cause of degradation of all phase sensitive signals including QAM signals is the phase noise that occurs in oscillators.

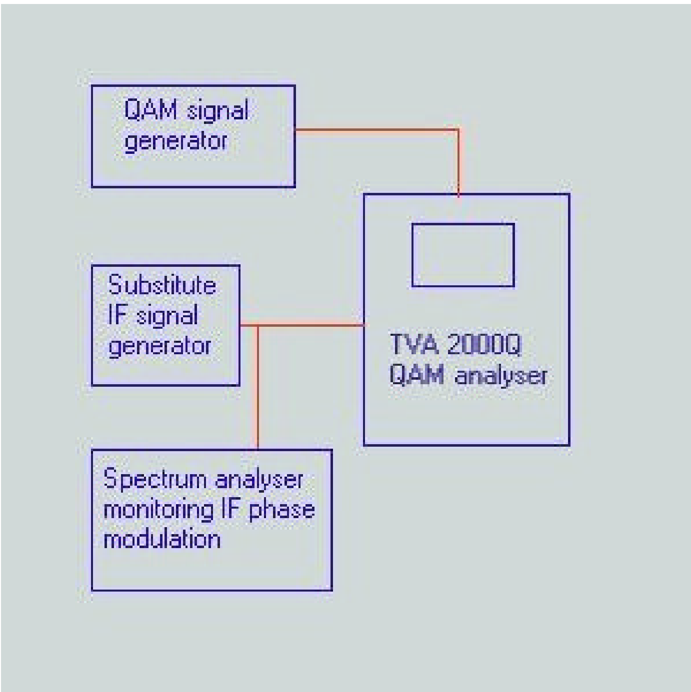
All signal level meters and analysers require at least one mixer and oscillator and most are double or triple superhet's which require 2or 3 oscillators.

When we started designing instruments for digital signals we needed to know the required phase noise specification.

A search of the literature found many references to the need for good phase noise performance but (as usual) no hard facts.

As a starting point we used good quality oscillators that had served us well in our existing analogue instruments. The results were quite good but left no margin and this started us on a very long process of refinement.

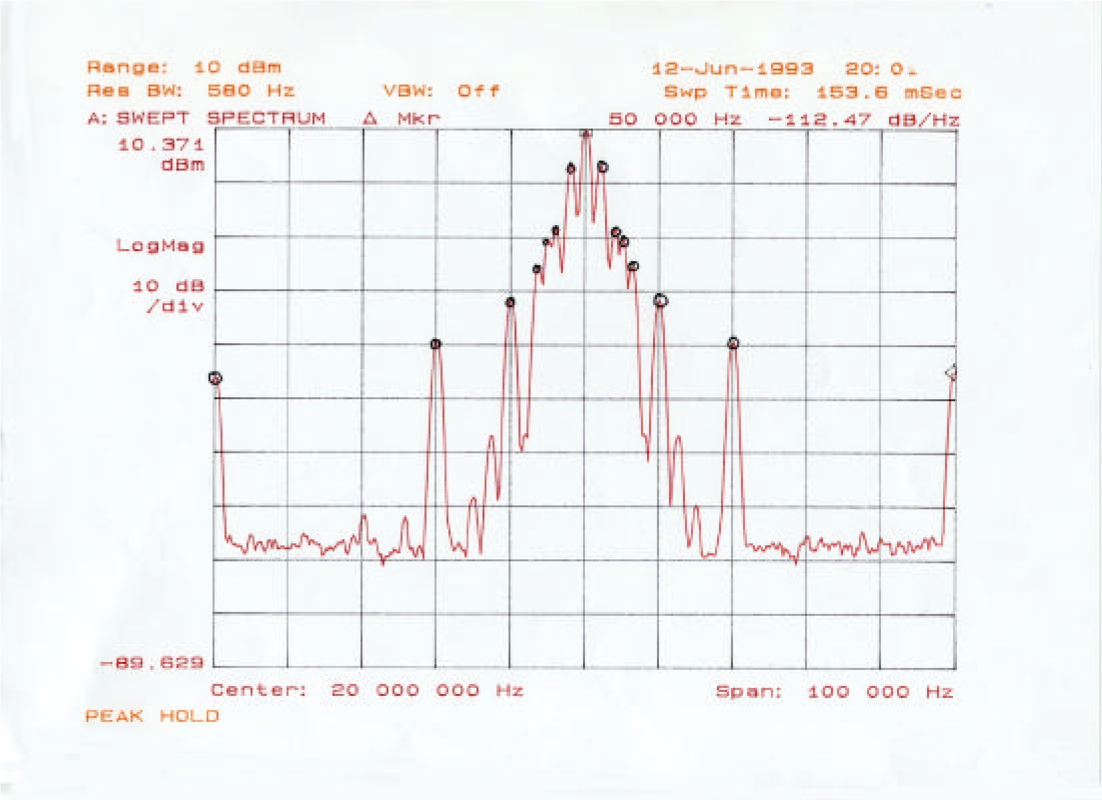
In order to determine the required phase noise performance for our instruments we carried out the following test on a prototype QAM analyser.




A reading of the MER was taken using the QAM analyser under test. This gave a MER of 37.5 dB.

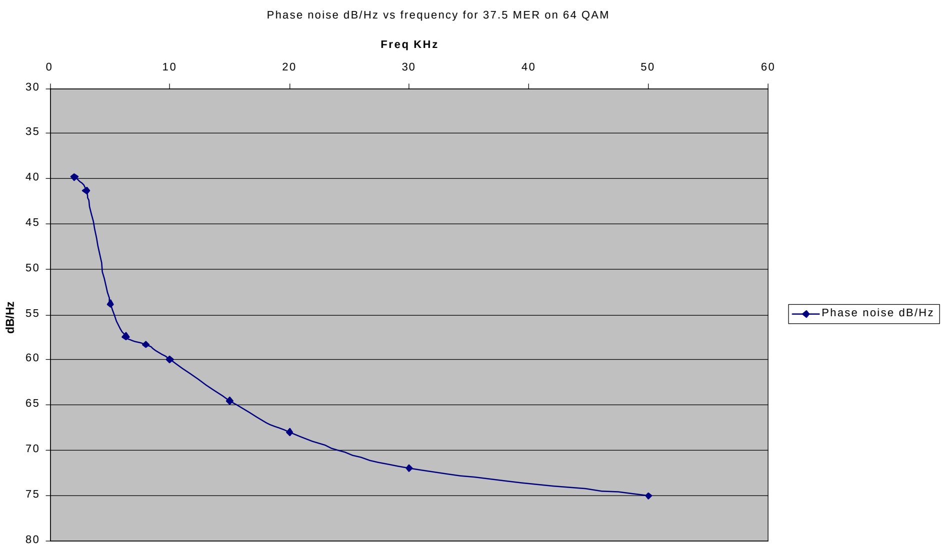
The second local oscillator in the QAM analyser was disabled and a signal from a high quality signal generator was injected as the second LO. this generator was then phase modulated at frequencies between 100Hz and 50KHz to simulate the effect of phase noise.

At each offset the phase modulation was increased until the MER fell from 37.5 dB to 37dB.

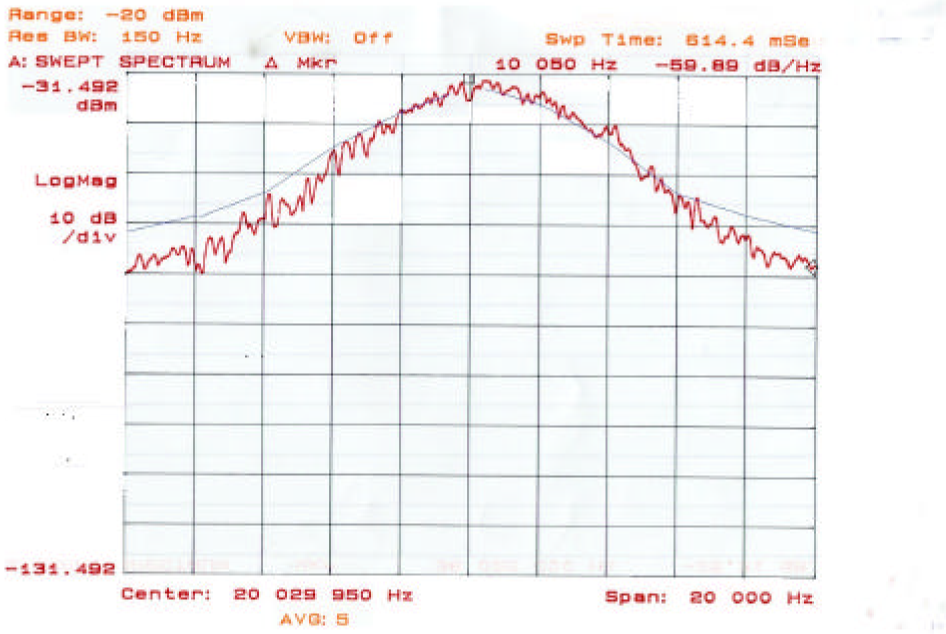



A Hewlett Packard HP3588A spectrum analyser which has an exceptional specification including a resolution bandwidth down to 1.1Hz and a phase noise of better than –115 dB/Hz was used to monitor the phase noise on the second local oscillator and this produced the graph shown. I emphasise the quality of the spectrum analyser as most spectrum analysers have more phase noise than the oscillators we were measuring!

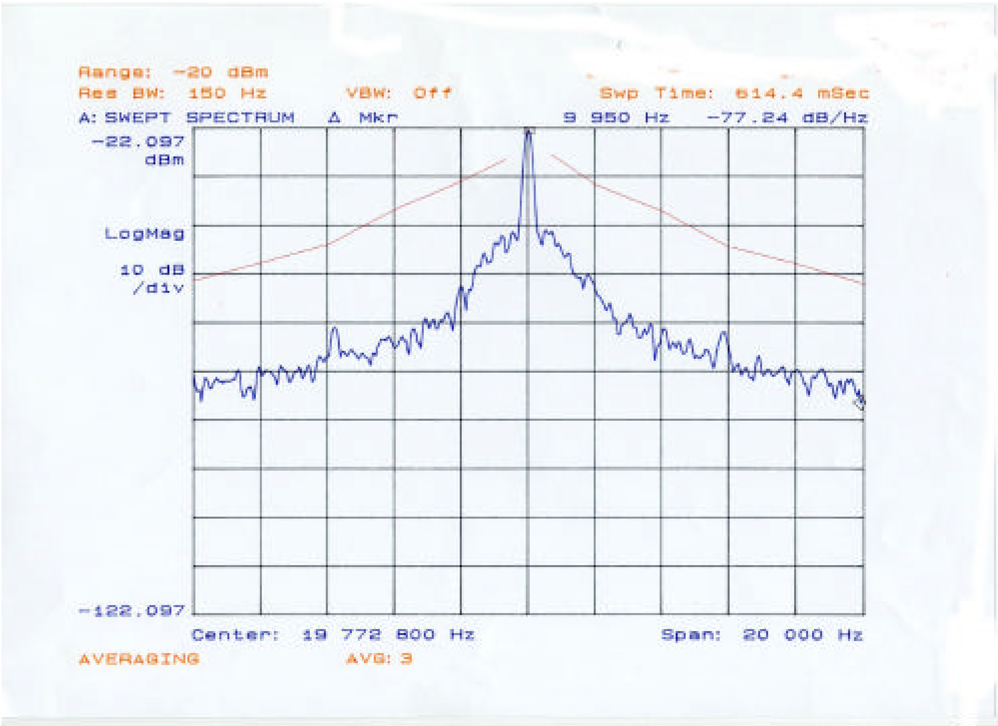
The phase noise at each offset was plotted to give the graph shown below



The graph shows the maximum phase noise in dB/Hz to give a MER of 37.5 dB. From these results we made a template which could be placed over our plots of oscillator noise to check their performance.




The plot above shows the original oscillator design, the margin is zero.




The second plot (above) shows what 3 months of concentrated design effort can achieve.

The 20-dB improvement in phase noise performance gives a very large margin.

After the blood sweat and tears we can be confident that the phase noise performance of the oscillators is not a limiting factor in our instruments.

**And so to BER (bit error rate)**

In an instrument with a QAM demodulator the Bit errors can be extracted from the demodulator chip and displayed as bit error rate. With a well-designed instrument giving good MER readings the BER readings should also be accurate.

For most purposes the MER reading is the reading of choice to asses network performance, MER is quick whereas on networks with good BER performance the time taken to get enough errors to give meaningful results is many minutes or even hours.

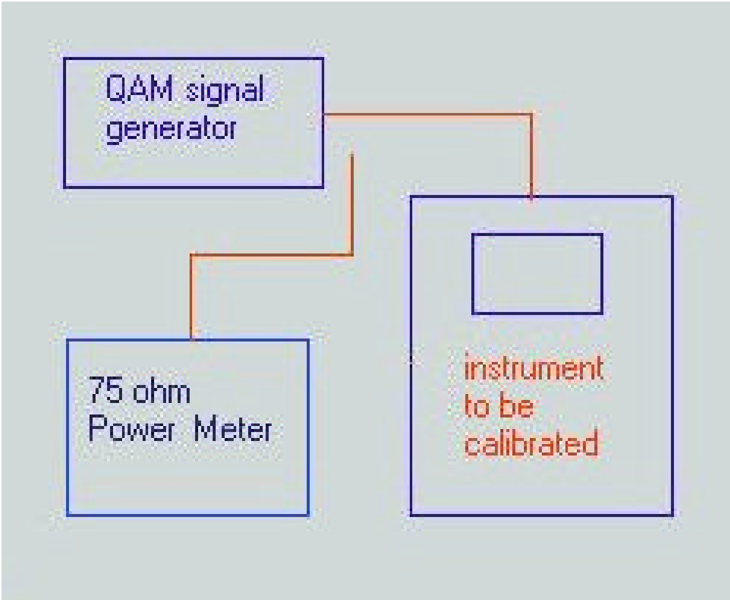
However both MER and BER measurements should be taken when checking and setting up laser links. When a laser transmitter overloads laser clipping can occur. In transistor RF amplifiers overload occurs as limiting or crushing of the output waveform this occurs over a relatively large change in input level and is a gradual process.

When a laser over loads and goes into clipping the laser diode actually ceases to oscillate momentarily (that is the light goes out) during this extremely short time data is not transmitted and is therefore severely corrupted. The time span during which this occurs may not be long enough to affect the MER reading as this averages over a longer time period. Where laser clipping occurs this can be seem by careful examination of the constellation display where isolated points can be identified. As the clipping becomes worse then the BER and MER readings degrade at the same rate.

**Measuring digital signal level**

As shipped we expect our instruments to be as good as the calibration methods allow.

Here is a simple method of checking the accuracy of any digital instrument.




Take a single digital modulator and feed the signal into a high quality calibrated power meter.
Having read the level on the power meter transfer the signal to the signal level meter the reading should be identical to that on the power meter. In order to check the accuracy of other levels an accurate calibrated step attenuator may be used to set the level.

The reason for using this method is that good quality power meters are not expensive and if they are not misused there is little to go wrong. The basic detector head relies on the heating effect of the RF signal on a thermistor or semiconductor element in a thermally balanced bridge circuit. Assuming the head is correctly matched in its housing the detector is in no way frequency sensitive until it reaches a cut off point. A DC amplifier and an indicator, which can be made very stable and reliable, follow this detector.

This method is preferable to using complex instruments like receivers or spectrum analysers, which have far more components, which may drift with time, temperature and vibration.

Swires Research use three power meters as our references and all three are calibrated and cross calibrated regularly and agree within +/- 0.2 dB up to 1GHz.

To ensure accuracy in our attenuators we use 4GHz attenuators which gives extra margin to ensure a perfect results at 1GHz.

These are our absolute standards and are used to set up automatic test equipment, the test equipment cycles the unit under test through every frequency and every level. This process would take days to do manually but can be achieve in less than 30 minutes when automated.

As a user a power meter can provide a quick and accurate confidence check, but full calibration is a job best given to the original equipment manufacturer, as he should have the necessary automated plant to carry out a full calibration at all frequencies and all levels.

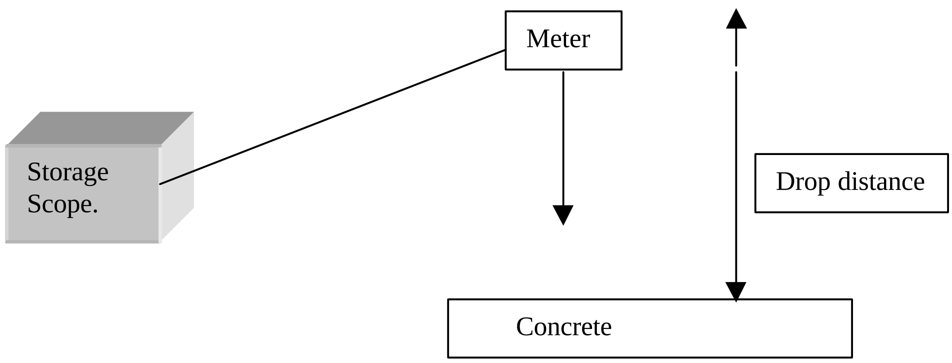
**Life in the real world**

But what do our customers do with our instruments in the field?

They break them!

Portable equipment will always take knocks .We decided to repeat our original drop tests to check the strength of our products.

We fitted two accelerometers at right angles in an ADC2000C installer meter with thin cables to transmit the signals to a storage oscilloscope.




The meter in its carrying case was dropped onto concrete from an increasing height and the storage scope recorded the g force registered by the accelerometers. After each drop the unit was checked for damage. The drops were repeated 2 times in both end-on and face down mode and the results are the highest recorded g at each height.

Results –

| Distance dropped | g force (peak) | Damage sustained |
|---|---|---|
| 2ft | 750 | nil |
| 4ft | 1250 | nil |
| 7ft | 3000 | nil |

The g forces are very high but the case remained undamaged and the meter remained in specification!

To put the g forces in context, the shock rating of a computer hard drive is typically 150 g. The generally agreed specification for the drop testing of a piece of electronic equipment packed for shipping is 2ft onto concrete.

Whilst the tests confirmed our belief that we had a very rugged case design it still left us with the mystery of why we received back damaged units.

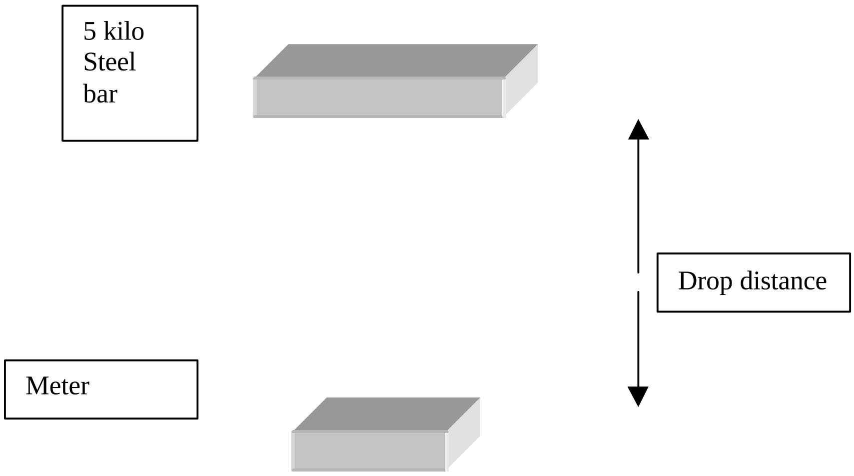
Surely not all could be from disgruntled employees flinging the meter under the wheels of a passing lorry!

Enquiries made amongst our contacts in the cable industry indicated that whilst no -one we spoke to had ever damaged one of our instruments, they had seen instruments damaged by other less careful installers.

The general opinion was that the damage occurred as follows-
Instruments are left in the back of a van and when a job is finished, large heavy reels of cable and or toolboxes are thrown into the back of the van and land on the meters.

**<u>Testing the theory</u>**

We decided to simulate the effect of a heavy object being thrown on the meter.
In order to do this in a controlled manner we dropped a steel bar onto the instrument. The bar measured 12 by 4 inches was 1 inch thick and weighed 5 Kilos (approx. 12.2 lb's).




As a control we also tested a similar size case made from a Tough A BS material and an old mobile phone

| **Object and plastic material** | Distance 5 kilo weight was dropped. | Damage sustained. |
|---|---|---|
| | | |
| Mobile phone (material not known.) | 2ft | Case cracked display damaged |
| Tough ABS plastic case | 2ft | Case cracked 1.5 inch piece broken away |
| ADC 2000C  signal level meter | 2 ft, g force off scale (greater than 4000). | No damage. Meter in specification |
| ADC 2000C signal level meter. | 4ft | 2-inch crack at front, metal panel bent but case held together. Meter working to specification. |

The damage sustained when the steel bar was dropped on the instrument from four feet, gave damage, which followed the same pattern as most of the damaged units returned from the field with the case cracked and the metal inserts loosened. Dropping the instrument did not cause damage. We feel that this indicates that the normal dropping or knocking of the instruments is not causing the problem. We can only speculate that heavy objects like cable reels or toolboxes etc. are being dropped onto the instruments.

We are proud of the fact that our electronic package survived all the tests and that the instrument was in specification at the end of the tests. **We do not however recommend that instruments be treated in this way!**

**Four years on, what have we learned?**

1, Take care when making signal to noise measurements.

2, MER is an excellent way of measuring network performance.

3, Beware of Laser clipping.

4, 256 QAM is coming! (Do we never learn?)

5, Don’t throw your toolbox on your test equipment!