Are all your bits in place?

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A lecture given during the 1999 CAI conference held at Heathrow.

In September 1997 I gave a lecture to the Society of Telecommunications Engineers titled, “ Measuring digitally modulated RF.”

At that time few measurements had been made outside the laboratory. The great British public had at that time been spared from the wonders of the digital TV revolution.

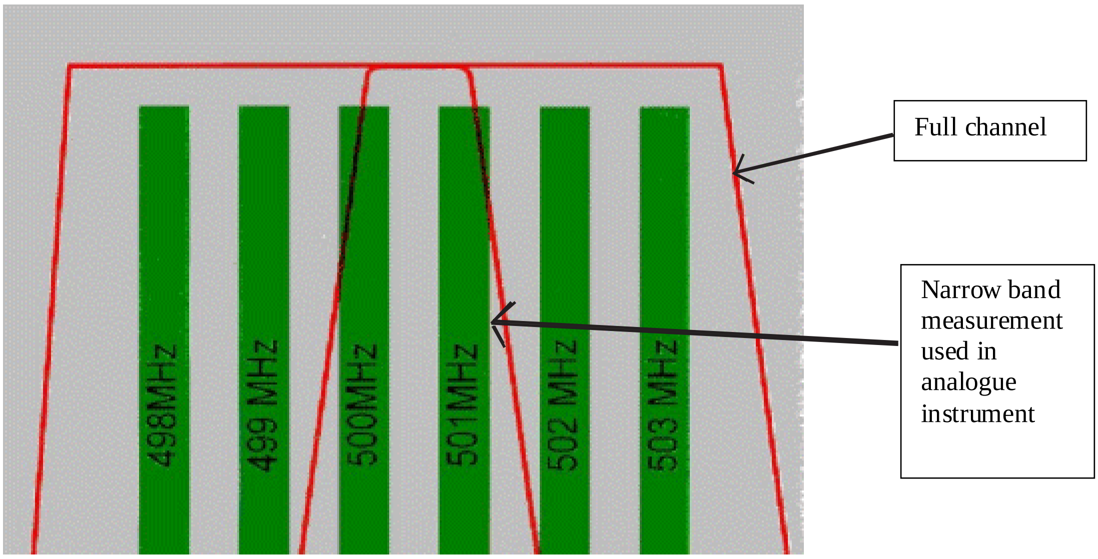
I am grateful for this opportunity to re -review the situation; the emphasis in this paper will be on digital Terrestrial and digital cable, both these systems are based on 64QAM modulation.

First I would like to briefly revisit the points I made 18 months ago

Bandwidth

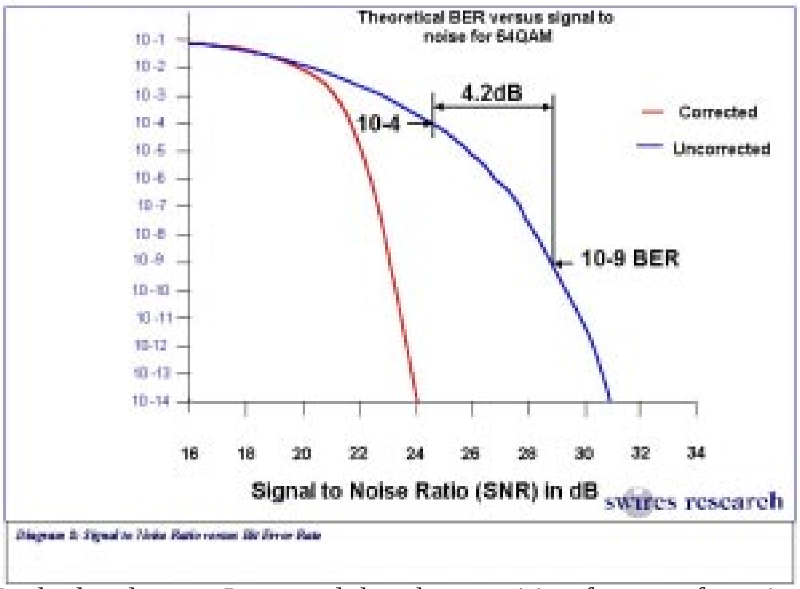
The Bandwidth of the measuring instrument must be known when measuring digital signals.

Instruments specifically designed to measure digital signals compensate for bandwidth and should measure the true power of the digital signal.



An analogue instrument only measures the area around the vision carrier, with a digital signal the power is spread over nearly the full 8MHz bandwidth

The digital cliff



In the last lecture I stressed that the transition from perfect picture to no picture would be very sudden. So no surprises there when we found that this really happens!

As can also be seen above a change of only 4.2 dB in signal to noise ratio represents a change from 1E 10^{-4} to 1E 10^{-9} in BER so that BER only indicates a problem close to the point of signal failure

Slide 6, time to measure BER.

The time required to make BER measurements

We readily compute the number of bit errors per second

Errors per second = data rate * bit error rate

A bit error rate of 1E-4, the generally agreed quasi error free point (just before it all falls over) for a typical data rate of 38.15 megabits

= 38.15 E6 * 1E-4 =3,815 errors per second

However at a bit error rate of 1E-10
=38.15 E6 * 1E-10 =0.0038 errors per second or 13 errors per hour.

To get good accuracy we need a minimum error count of about 50 errors

At a bit error rate of 1E-9 we get only 2.28 errors per minute, so we need many minutes to collect accurate BER data

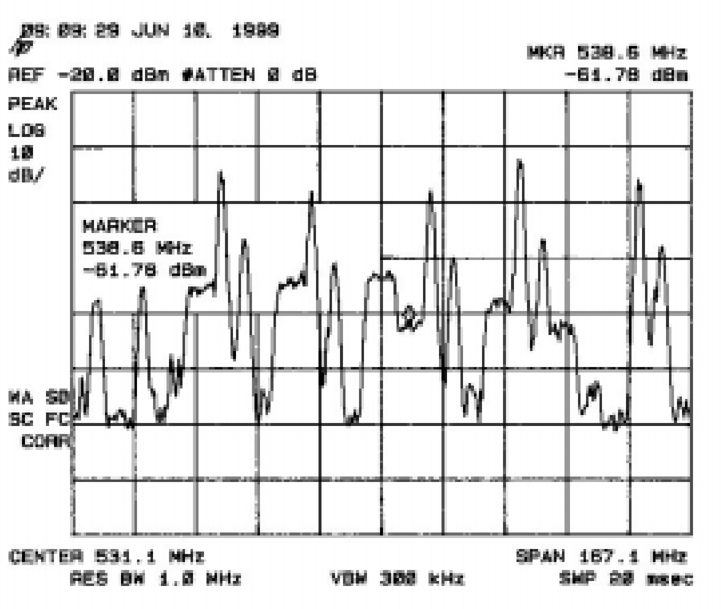
This is a factor when measuring good bit error ratios. If this type of measurement is required then it is preferable to leave the bit error rate tester in place with a data logger for several hours or days.

My conclusions. 18 months ago are outlined below.

*Bit Error Rate
Good bit error rates take a long time to measure accurately and have a limited measurement window.

*Signal to Noise
Measurements of signal to noise ratio give a very good indication of the quality of the cable network, and it’s margins for digital signals.

Now I would like to look at the present situation with digital terrestrial and think about the imminent arrival of digital on our cable networks.



The plot above shows the UHF signals radiated from the Crystal palace transmitter. Suddenly we have six new digital multiplexes.

What have we learned in the last six months? (Apart from saying never again!)

Low cost instruments capable of measuring digital signals have become readily available from at least two suppliers for the last six months. These measure digital signal power and signal to noise ratio.

In the case of our own instrument, feedback from our customers is good. In most installations ensuring an adequate signal level and a good carrier to noise ratio produces a good result.

However there will always be the exception;

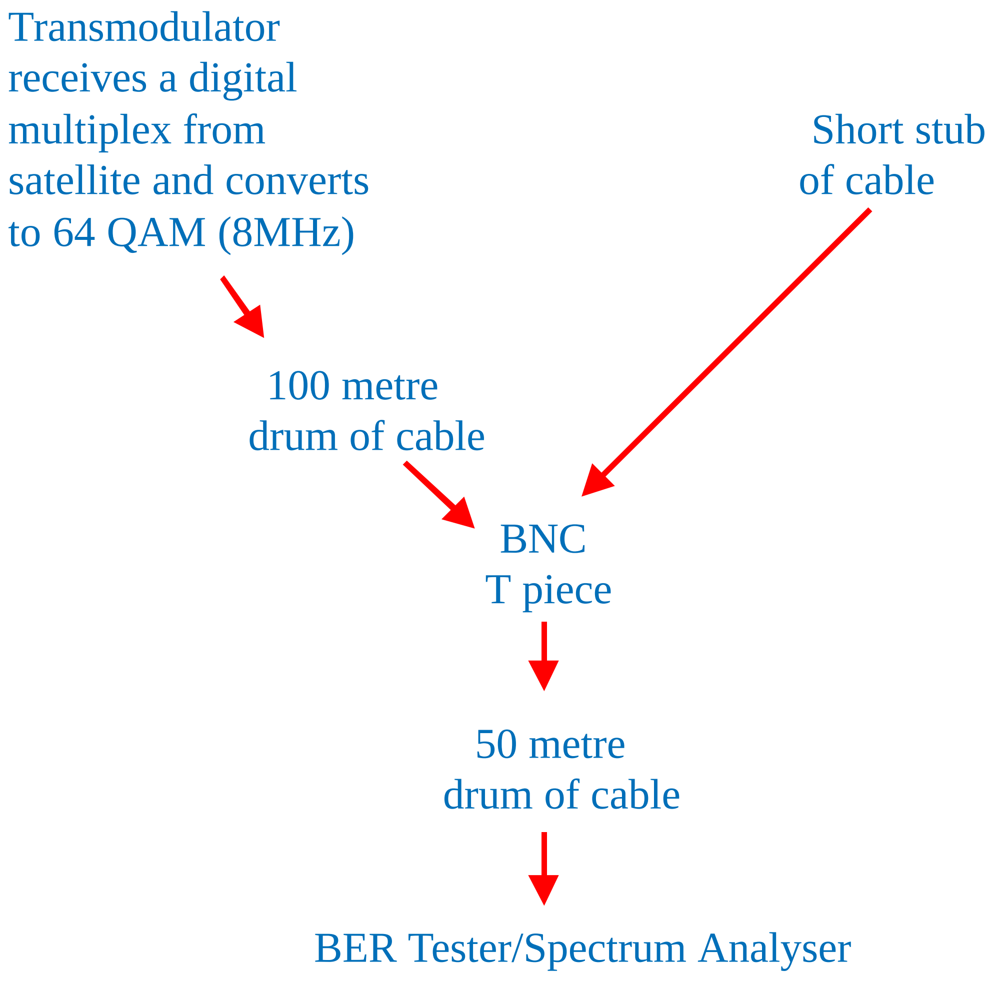
There is a good signal level and a good signal to noise ratio but no picture! So what has gone wrong?

First of all change the set top box, not all are perfect!

Still no picture!

Now it has been reported that poor taps and bad mismatches can cause problems with digital signals due to reflections.

Looking at the theory this did not seem likely. No work has been reported on this subject and so we decided to set up a test network in the lab and make measurements on a network.



The diagram shows the test network which we set up.

The purpose of the T piece was to simulate a very bad, completely mis-matched two-way splitter. The short stub could be open or short-circuited and varied in length to provide a worse case open or short circuited line to a subscriber tap off.

First the Response and BER were tested with no T piece at the junction of the two cable drums. And the results noted.

The second test was with the BNC T piece added.

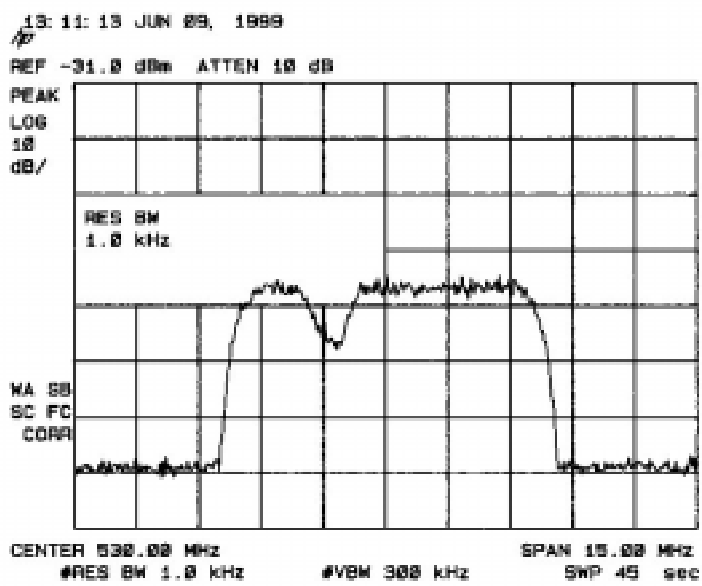
In spite of our best efforts, including changing the lengths of cable on the T piece for lengths of between 0.5 and 10 metres on the stub we found no change in the BER.
Clearly very bad reflections were occurring but these are too close in time to affect the integrity of the digital data. Multiple reflections could be a serious problem but if these occur they are subject to the attenuation due to the loss incurred in many trips up and down the cable.

By the time the reflections are spaced in time by a sufficient amount due to the time taken to reflect up and down the cable they have been attenuated enough to make them too small to cause errors.

If the lengths of cable were made longer then the extra attenuation would cause attenuation of the reflections and reduce the effects.

The only point at which we found a problem was when I left an adapter about 1inch long on the end of the T piece. The BER tester would not lock and a set top box would not lock. If this had occurred in a system it would be a very puzzling fault

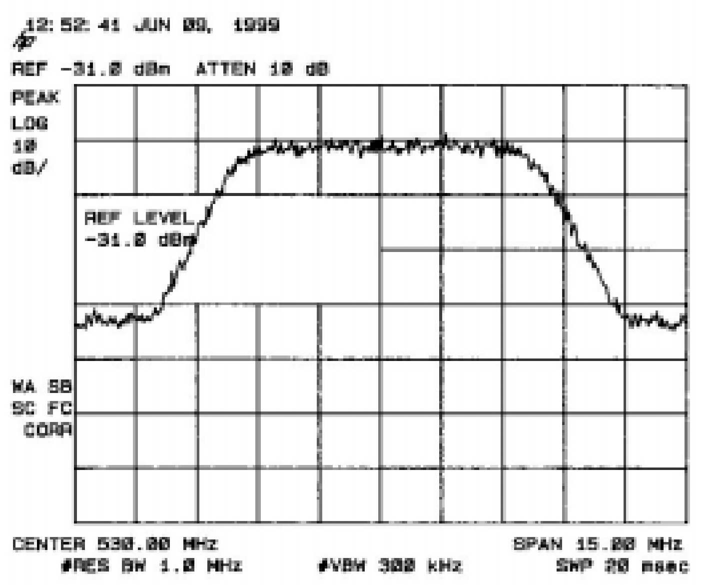
We checked the frequency response at the end of the cable.



As shown above we found a beautiful hole near the middle of the channel. This would be a difficult fault to find with anything but a spectrum analyser. A level meter would not revel this problem.

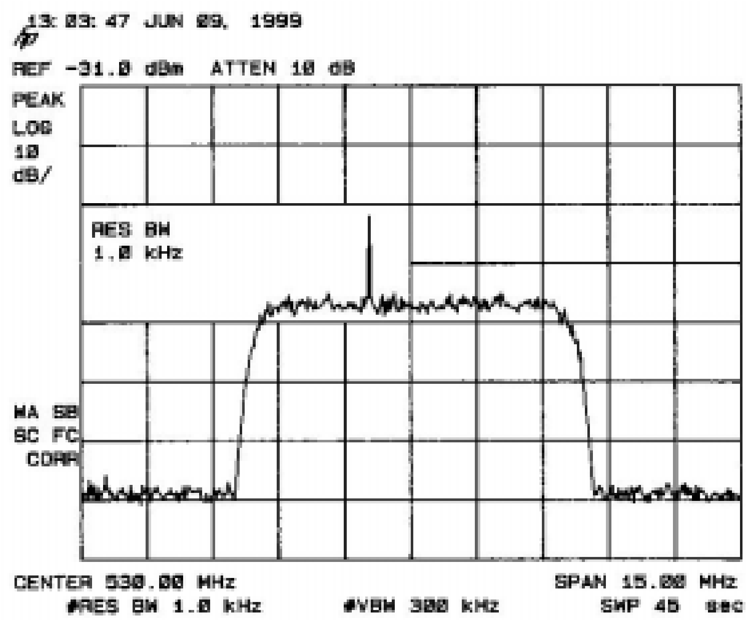
Of course once again greater care with the installation and the use of good quality cables accessories will stop the problem before it starts. However we concluded that reflections due to mismatching did not affect the digital signals.

But we digress We started talking about a seemingly perfect signal;
Like this signal.



Better than 30dB signal to noise ratio but the set top box would not lock neither would
a BER test set so no clues there!

Maybe something is lurking below the surface of this nice looking Digital signal.



All is revealed!

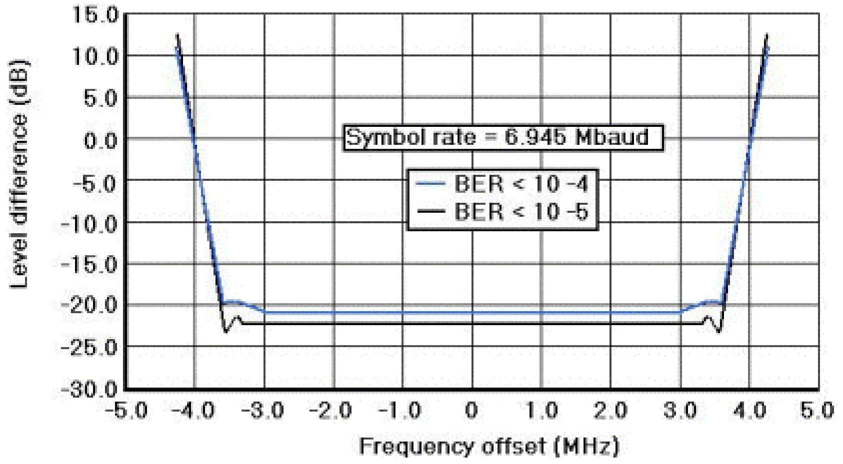
How did we do that?

We used a useful method to find a spurious signal in a QAM channel.
The first plot showed the original signal, which would not lock. This appeared to be perfect on the spectrum analyser.
We reduced the bandwidth of the analyser from 1 MHz to 1KHz, which should give a theoretical reduction in noise of 30 dB, the result is shown in this slide. The noise floor and the QAM signal have dropped by about 27dB and revealed is a unwanted signal at 529 MHz.

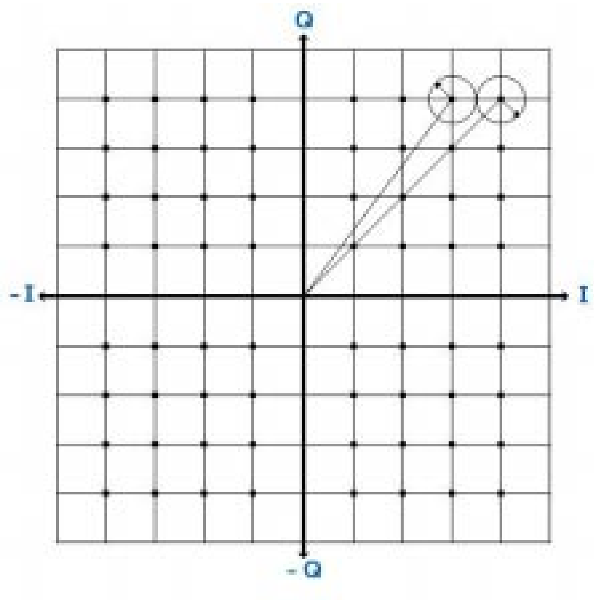
This being only 10dB down on the QAM channel measured at 1MHz it is quite sufficient to completely unlock the QAM channel.

The above test does need a high quality analyser with provision of a 1KHz bandwidth or lower but is a valuable diagnostic measurement.

The spurious signal may be from a beat product or co-channel interference from an analogue transmitter.



This diagram shows the protection ratio required for a 64 QAM cable channel, we have found that any spurious signals should be greater than 22dB down on the digital channel.

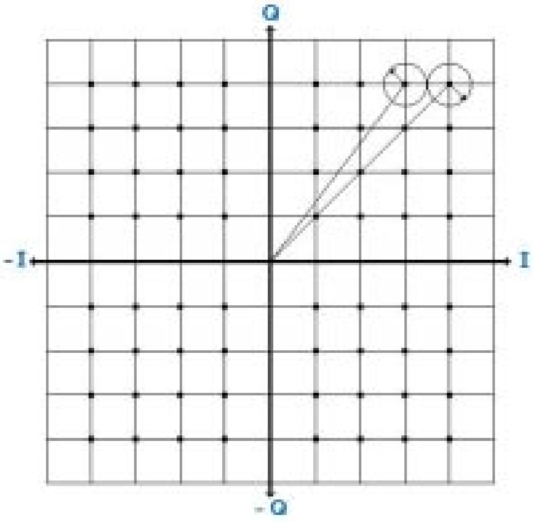


The diagram above shows a constellation diagram, which is a representation of the position of the bits in a 64QAM channel.

The photograph shows a vector-scope of the type widely used by the broadcast industry to set the gain and phase of a TV colour subcarrier on an analogue transmission.

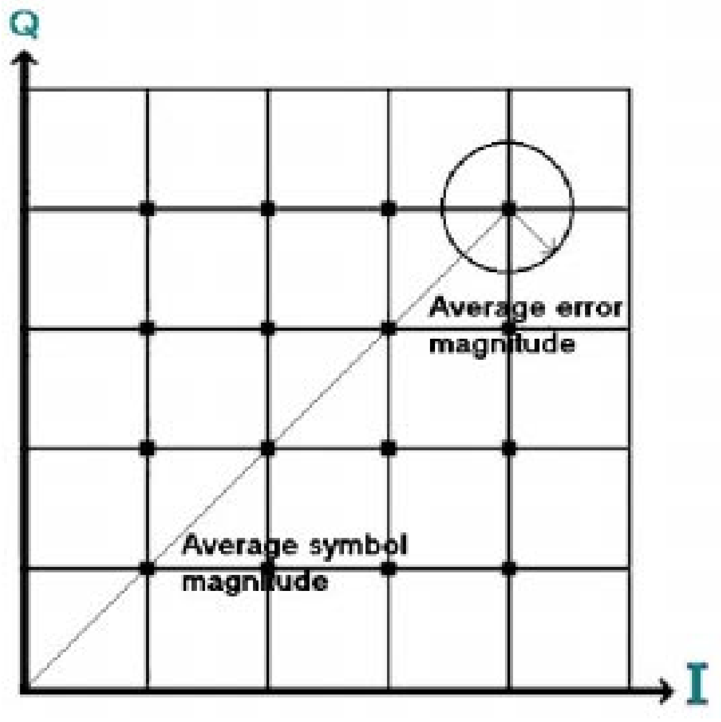
The circular display shows phase from 0-360degrees. The amplitude of the signal is shown by the distance of the points from the centre of the display.

The constellation diagram is the digital equivalent of the vector-scope.



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 diagram below shows one quarter or quadrant of the display.



It has been said many times that a picture is worth a thousand words, a constellation diagram gives a picture .

The great benefit of a constellation diagram is that it reveals deterioration before the failure of a digital signal. As we all know the digital picture on the set top box can be perfect until the exact point of failure when the system no longer locks .

With a digital set top box we have no equivalent of the increased noise which we see on an analogue picture, which lets us visually, assess signal quality.

The constellation diagram is a very visual tool, at a glance we can asses the quality of a 64 QAM signal.

Instruments capable of showing constellation diagrams, have because of their cost and size been restricted to the realms of the development engineer.

However the availability of faster processors and improved software is now making it possible to consider incorporating constellation diagrams into modestly priced portable equipment

The constellation diagram is a very visual approach but from it we can automatically extract a numerical parameter called MER.

Modulation error ratio is often interchanged with signal to noise ratio

MER can 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 SNR are equivalent.

The ETSI document ETR290 gives the relationship between SNR and MER as
SNR in dB =MER in dB. (If the only significant impairment is gaussian noise)

In the DVB environment it is possible to measure signal to noise ratio by measuring the ratio of the signal power to the noise power in the next empty channel.

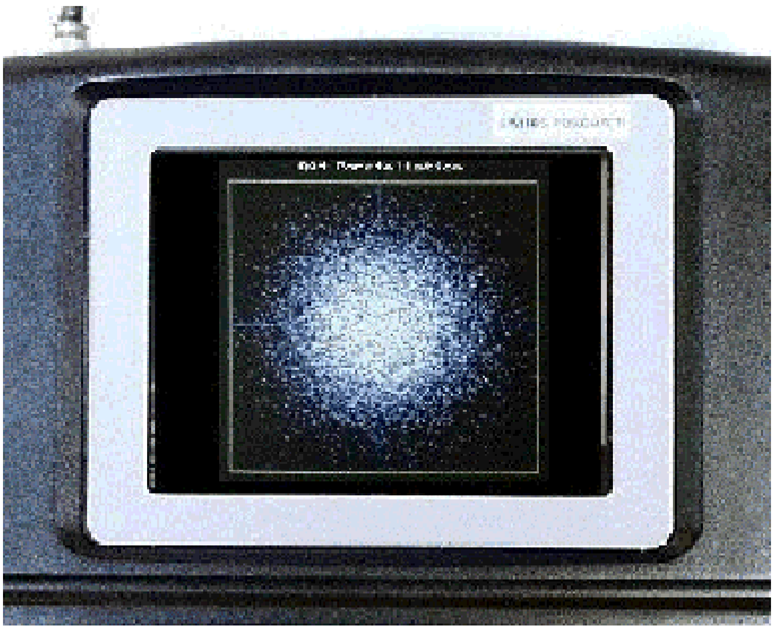
Our commercial friends are rapidly filling up all the channels on our cable networks and this is where MER becomes a very valuable measurement.

MER is a noise measurement made within an active channel.

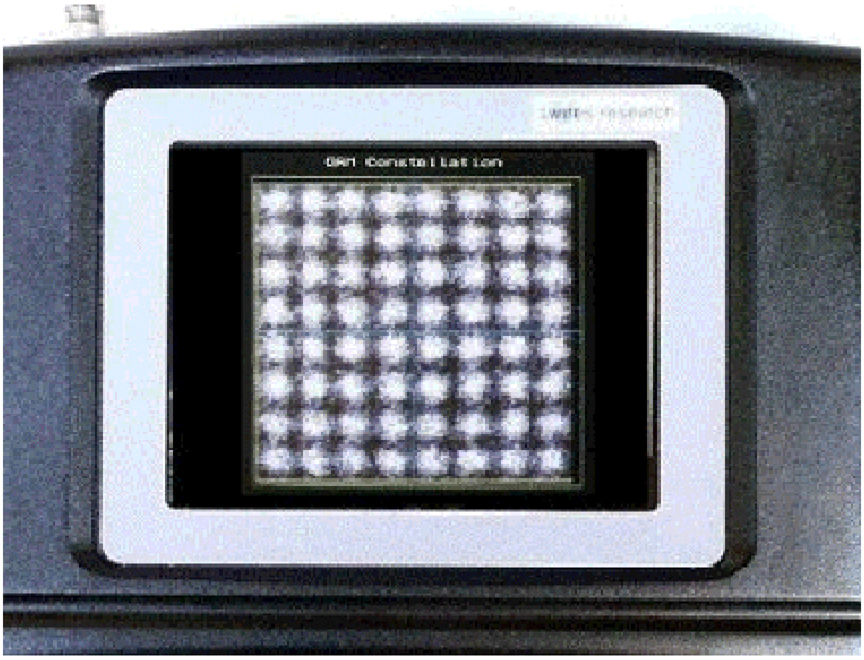
BER can also be extracted from the demodulator used to give the constellation diagram. For low bit error rates the measurement time is long. However having demodulated the signal it is worth indicating the BER. The extraction of the BER is quite straight forward this should be done before and after the forward error correction circuits to see how hard the FEC is working, with a poorer signal the FEC has a harder task.

A prototype QAM analyser.

The screen shot above from the QAM analyser shows a good clean signal with about 30dB signal to noise the smaller the dots the better the signal to noise ratio

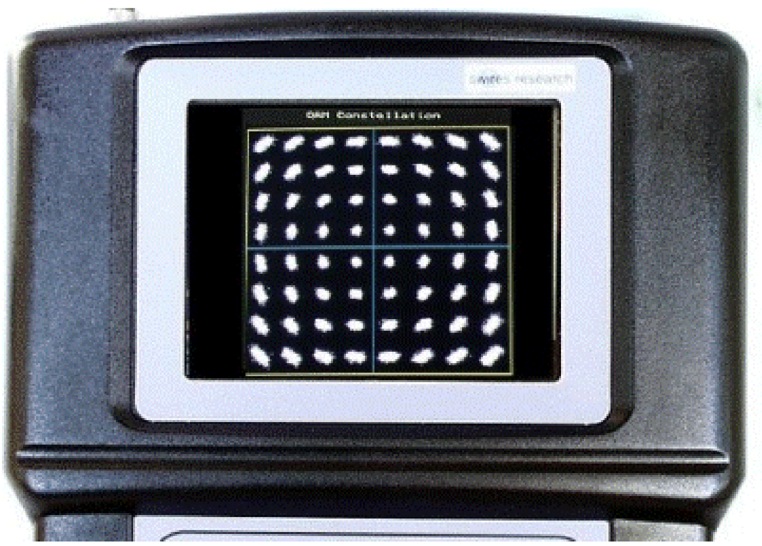


This is what happens if the signal does not lock. If you see this don’t unpack the set top box yet!



The constellation has locked,

This would give a perfect picture but for how long? The signal to noise ratio is very marginal, this is a good example of how quick and intuitive this measurement is.



A number of other effects are also recognisable on a constellation display,
Phase noise is visible on this display this is the circular effect which is most pronounced at the perimeter. Phase noise is most likely to be a headend problem and is not caused by normal transmission down a network.

This we have named the "polo mint" effect

This is caused by an in channel spurious analogue signal at approximately 25 dB down on the QAM signal.

The screen photograph shows the point at which the constellation locked. Once again the picture on the set top box would be perfect. Using the constellation monitor we can trace the offending signal before it causes trouble.

Summary

Power and signal to noise measurements provide a very good low cost guide to signal quality when measuring digital signals.

The use of a spectrum analyser can reveal Problems which are not apparent with a Simple meter.

The constellation diagram and the use of MER Are very powerful tools. Expect to see these In the next generation of portable instruments.