Testing Frequency Multipliers and Dividers

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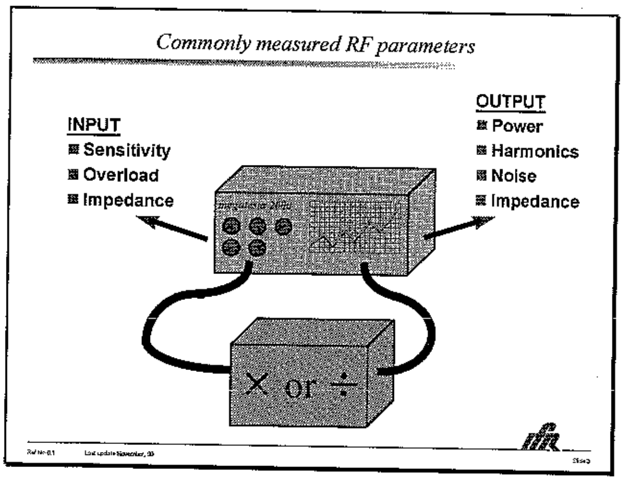
Introduction

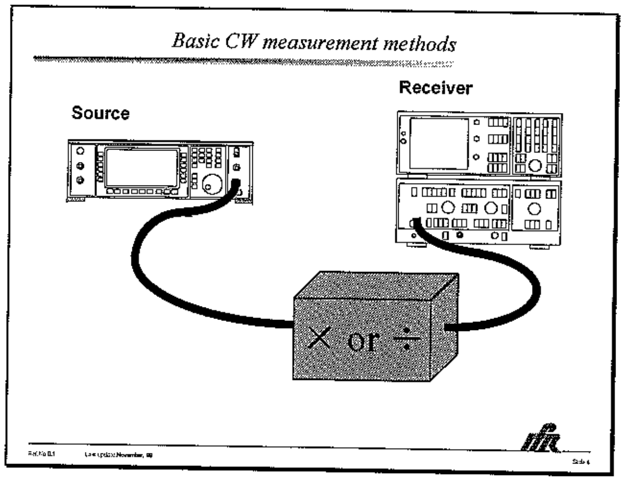
Frequency dividers and multipliers are key components of modern RF and microwave systems. They are generally used in signal generation and frequency synthesis applications.

This workshop reviews current methods of measuring various key RF parameters and introduces some novel swept techniques using the IFR 6840 series microwave system analyzers. Some screen shots from the demonstrations are included in these notes.

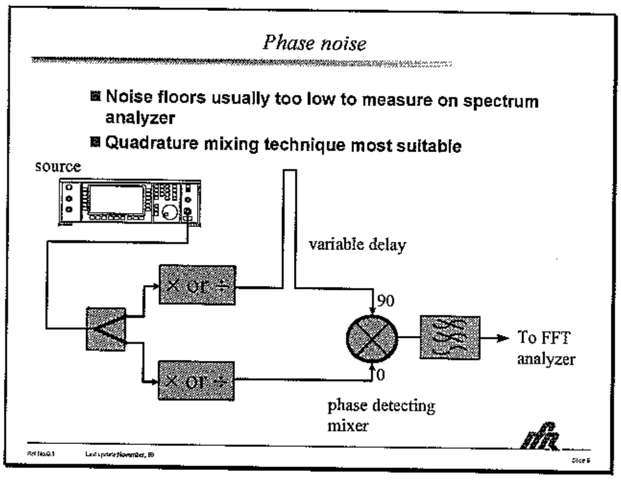


RF measurements on multipliers and dividers can be separated into input and output tests. The frequencies of these measurements differ by the divide ratio or harmonic number of the device under test. The parameters are generally presented as functions of frequency, so ideally a swept measurement is required. We'll start by reviewing how some of these measurements can be made using common laboratory equipment.

Basic Measurement Techniques



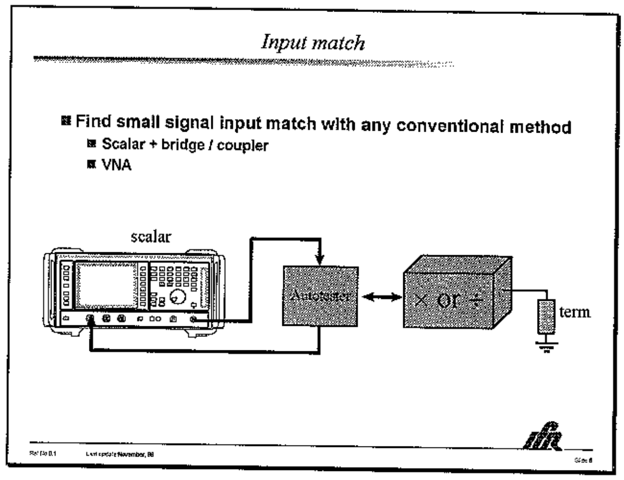
A signal generator and spectrum analyzer are all that is needed to make sensitivity, overload, output power and harmonic measurements at spot frequencies. If the signal generator can be swept, the maximum hold facility on most spectrum analyzers can be used to produce a graph of output power or harmonics over a range of frequencies. This can only be done over a small frequency range to prevent the harmonics overlapping.



The phase noise of dividers and multipliers is a major concern especially when they are the building blocks of frequency synthesizers. The output phase noise of a multiplier or divider is ideally given by

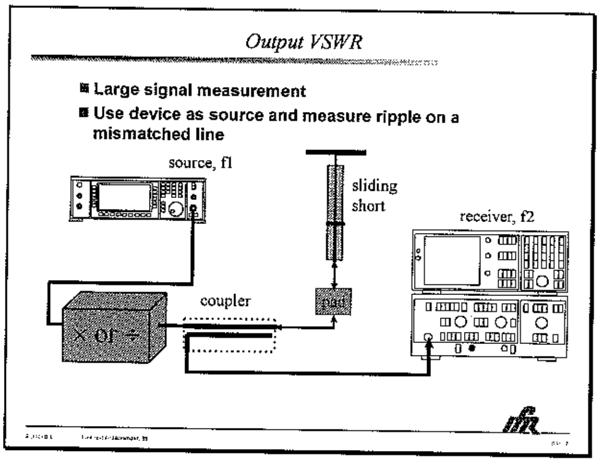
$$L_{OUT} = L_{IN} + 20\log\left(\frac{\text{output frequency}}{\text{input frequency}}\right)$$

where L_{IN} and L_{OUT} are single sideband phase noise in dBc/Hz. Dividers improve the phase noise whereas multipliers degrade it. In real devices, the output phase noise is limited by a floor. This can be measured by many methods, but most of these require a reference signal better than the device under test. This problem can be overcome with a quadrature mixing method. The devices are measured in pairs. The signal generator phase noise adds to both legs of the measurement, and is cancelled at the phase detector, leaving just the sum of the noise from the two devices. If three devices are available, they can be measured in all combinations to reveal the noise of each individual device. It is particularly important to ensure only the desired output harmonic reaches the phase detector. The phase detector can be calibrated with a beat note method using another signal generator.



Complex RF subsystems are often designed by a team of engineers. To reduce integration problems, input and output return loss are commonly specified for each block of circuitry.

The input match of a divider or multiplier can be measured over the input frequency range using any conventional technique. The example above shows an autotester (return loss bridge) and scalar analyzer. When using a broadband device such as an autotester to measure dividers and multipliers beware of backfire of the output frequency or harmonics causing errors. Ensure that the power at the device input is correct during the measurement, as the input match is a function of input level.

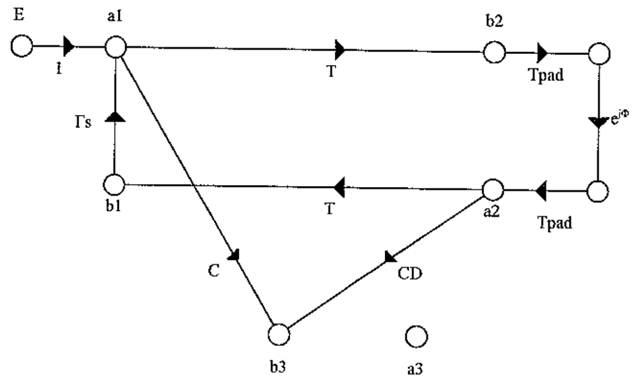


When measuring output return loss, it is important that the multiplier or divider is in its normal operating state. A small signal measurement with an autotester or VNA may give false results, as the operating conditions of the non linear parts of the device will be different. The device output is used as excitation for the measurement. A mismatched line is used to reflect power back to the device and the standing wave pattern is used to determine the output match.

In the above example, the output is loaded with a short circuit. This may cause problems with some devices, especially digital dividers, which could stop running. In this case, a pad can be inserted before the short to provide a controlled mismatch. The forward power on the line is sampled with a directional coupler. By adjusting the length of the mismatched line, the maxima and minima of the standing wave can be observed on a spectrum analyzer tuned to the output frequency. The ratio of maximum to minimum is the VSWR on the line. The return loss of the device under test is given by

$$RL(dB) = 20\log\left[\frac{VSWR+1}{VSWR-1}\right] - 2L_{pad}$$

where Lpad is the loss of the pad in dB. Errors in this measurement can be analysed with reference to the following simplified flow graph.



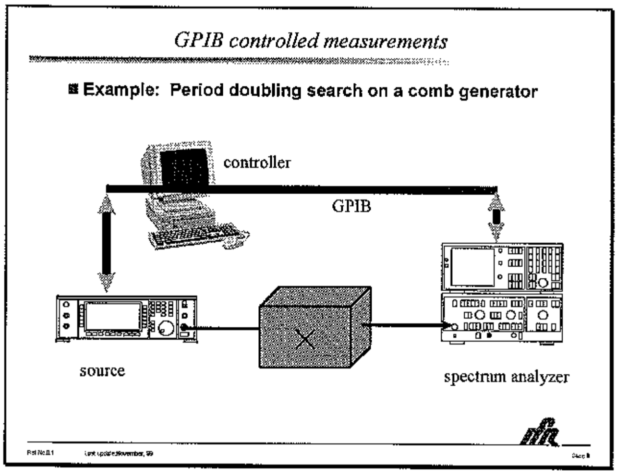
coupled port (assume matched)

DUT reflection coefficient Γs
Coupler transmission coefficient T
Coupling coefficient C
Coupler directivity D
Pad transmission coefficient Tpad
Sliding short reflection angle Φ

The sliding short is modelled as lossless. The analysis will not be included, but the main result is summarised in the following table. This assumes no pad.

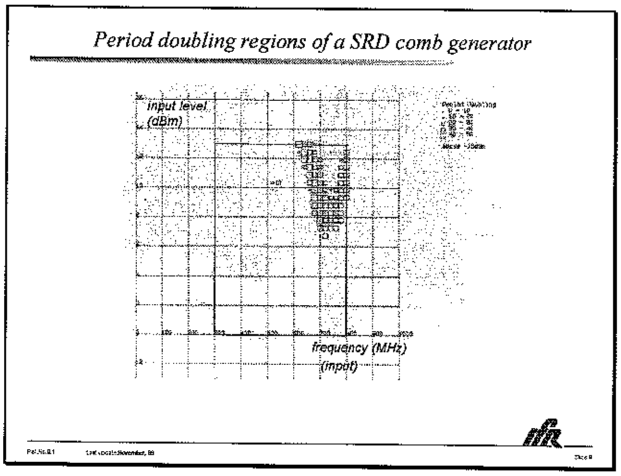
Coupler directivity	Uncertainty in VSWR
20dB	±22%
30dB	±6.5%
40dB	±2%

As a rule of thumb, the coupler directivity needs to be 10 to 20dB better than the output return loss being measured.



Considerable time can be saved by automating the preceding measurements with GPIB compatible instruments and a controller. This technique is very flexible, and a system can be contrived to measure almost any parameter verses frequency, power, time etc.

As an example, the above figure shows a relatively simple set-up to search for an interesting characteristic in a comb generator. The time varying capacitance in a SRD based comb generator makes it easy to inadvertently produce a parametric amplifier. The parametric gain can cause peaks in the noise floor, or even oscillations, generally at half the input frequency, and is often referred to as period doubling instability. In trying to construct a multiplier, a divider has been produced!



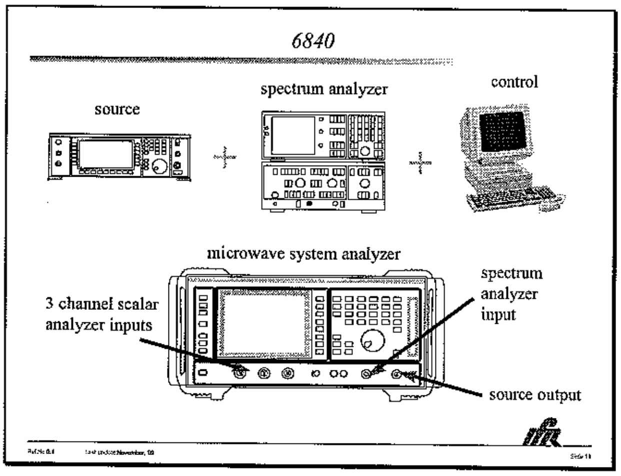
Considerable problems were experienced in proving the effect had been eliminated as it happens over a narrow range of drive levels and frequencies. A GPIB controlled system was assembled to plot regions of period doubling against frequency and drive power - a typical result is shown above. This saved substantial development time.

Fast swept - frequency techniques

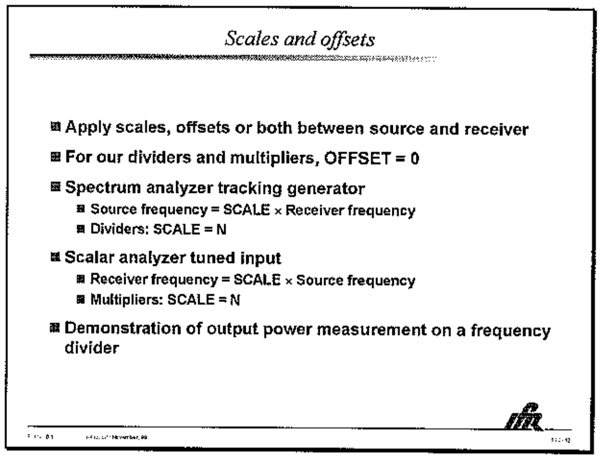
RF engineers like to see plots of characteristics against frequency. Even CW multipliers need to be characterised over frequency to allow for component tolerances and temperature change. For manufacturing, real time tuning and rapid development applications, fast swept measurements are desired.

We have already discussed one fast swept measurement - input return loss - but how can we measure output power and harmonics?

A scalar analyzer can be used to measure divider and multiplier output power, but the high levels of harmonics can cause large errors with broadband detectors. Most spectrum analyzers with tracking generators and vector network analyzers cannot handle frequency conversion devices without external hardware. What is needed is a synchronised source and receiver with the required frequency relationship. The IFR 6840 microwave system analyzer can do just that.



The 6840 contains a signal generator, spectrum analyzer and scalar analyzer. In most tracking generators, the signal is derived by mixing the spectrum analyzer LO. In 6840, the source and receiver are independent, so any frequency relationship can be obtained in the range 10MHz to 24GHz.

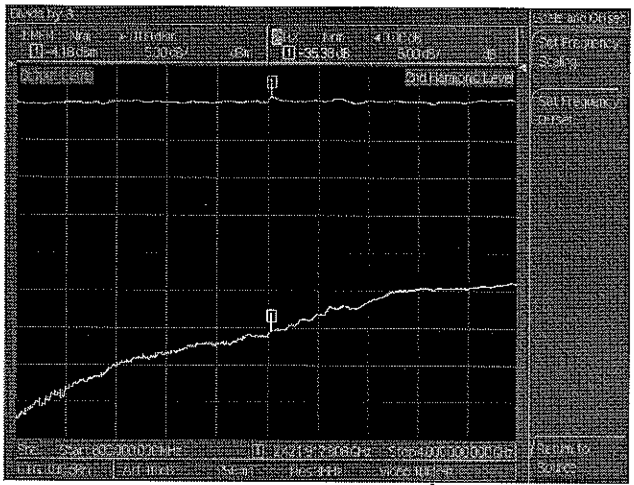


The relationship between the source and receiver frequency is determined by a scale and offset control. The instrument has been broken into two modes: spectrum analyzer and scalar analyzer. For dividers and multipliers, the offset control is set to zero. The offset can be used to characterise mixers.

In spectrum analyzer mode, the frequency range at the receiver is entered and the source frequency is scaled and offset. The instrument acts like a spectrum analyzer with a scale and offset tracking generator. This mode is convenient for measuring dividers as the scale is simply the divide ratio.

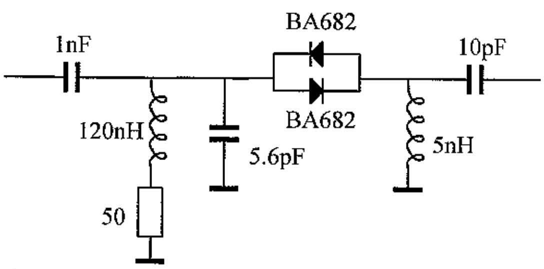
In scalar analyzer mode, the source frequencies are entered and the receiver frequency is scaled and offset. This is convenient for frequency multipliers, where the scale is the harmonic number. The instrument acts like a scalar analyzer, except the input is tuned and of high dynamic range. The tuned input can be combined with scalar detectors to measure conversion gain.

As an example of the spectrum analyzer mode, the following figure shows a screen shot of a 6840 measurement of the output power of a frequency divider. The plot is overlaid with a swept measurement of the second harmonic level.

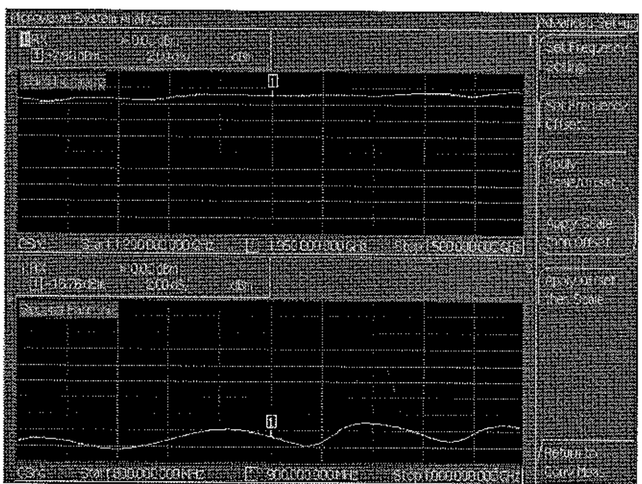


Divider output level and 2nd harmonic level measured on 6840

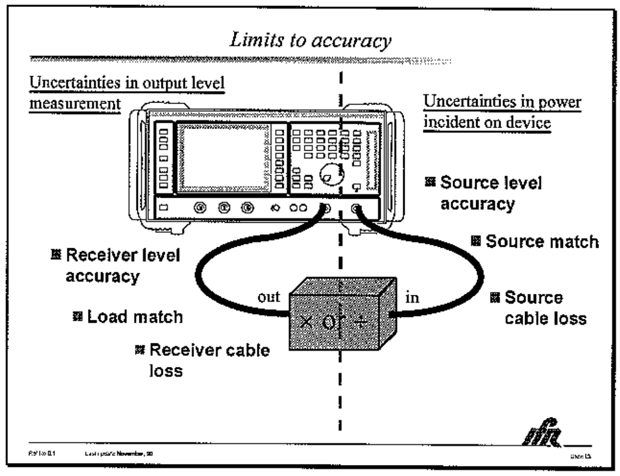
As an example of the scalar analyzer mode, the following screen shot shows a comparison of the 2nd and 3rd harmonic measurement of a multiplier. This circuit generates a signal rich in odd harmonics and suppresses the even harmonics. A dual channel measurement is shown. These measurements are live, and swept alternately.



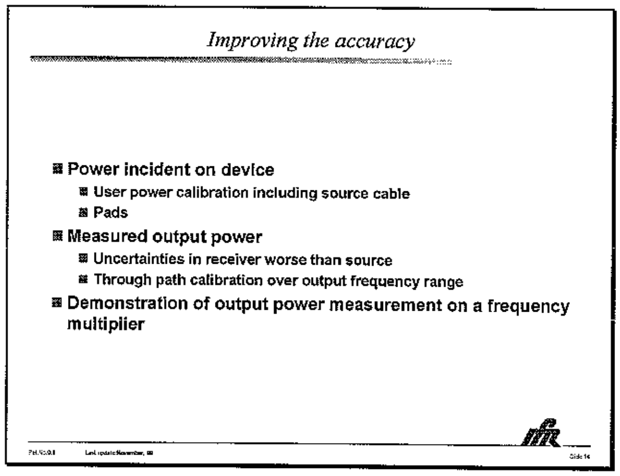
Odd harmonic generator circuit



Multiplier 3rd harmonic (top) and 2nd harmonic (bottom) measured with 6840



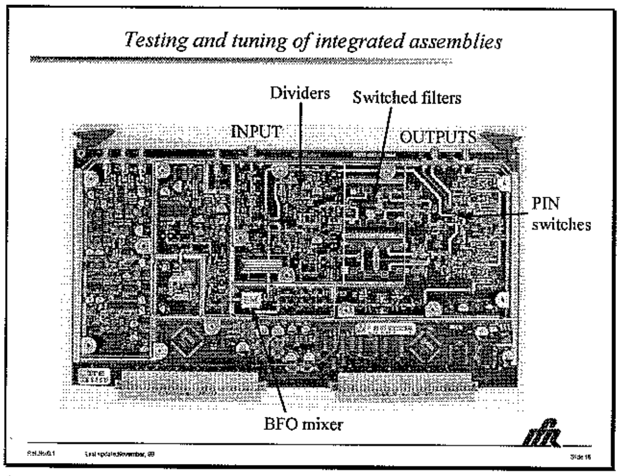
Accuracy considerations for multiplier and divider measurements must be split in two. At the device input, the source level accuracy, cable loss and source match are the dominant factors in uncertainty of incident input power. At the device output, receiver level accuracy, load match and cable loss limit the accuracy of the output level measurement.



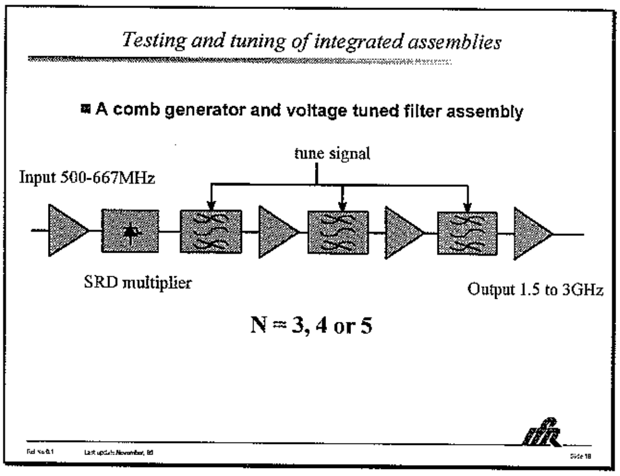
The input cable loss can be compensated for by performing a user power calibration at the end of the cable. The instrument automatically sets the front panel level high enough to compensate for the cable loss. The source match can be improved by increasing the power level and adding 50 ohm attenuators.

A through path calibration can be performed over the source or receiver frequency range. The choice depends on the uncertainties at each side of the device under test. The

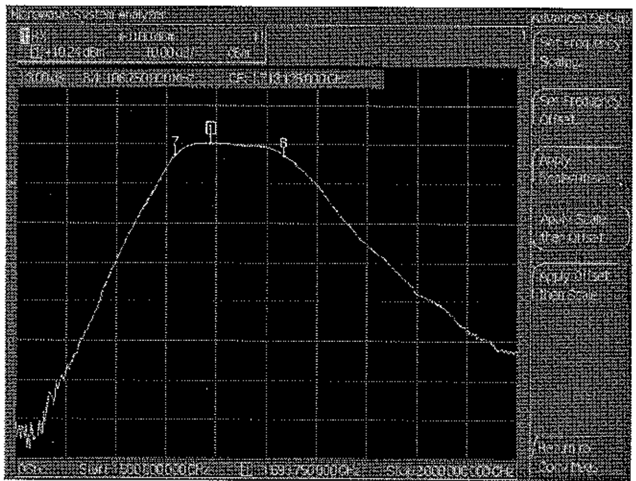
receiver level accuracy is worse than the source level accuracy and a calibration over the receiver frequency range is most suitable. This reduces the spectrum analyzer reference level uncertainty to approach that of the source.



Frequency multipliers and dividers are rarely stand alone devices, and are usually part of an integrated system. The above slide shows an example of such a system - in fact this is a PCB from the 6840. The board takes an octave signal from a synthesiser (1.5-3GHz) and divides or mixes to produce lower frequencies (10MHz-1.5GHz). The dividers on this PCB are connected directly to filters and distribution switches. 6840 can be used to perform a swept measurement of the entire signal chain. The speed of the measurement allows the effect of adjustments to the circuit to be seen in real time.



As an example of real time tuning, the following screen shot shows the third harmonic response of a comb generator / voltage tuned filter assembly. The centre frequency and shape can be observed as the tuning voltage is adjusted.



Real time measurement of 3rd harmonic of a comb generator / voltage tuned filter

Conclusion

This workshop has reviewed techniques for measuring the key parameters of frequency multipliers and dividers. In particular methods for measuring phase noise and output match have been studied. GPIB controlled set-ups have been mentioned and the flexibility of such techniques highlighted with the example of searching for period doubling. A novel, fast, swept frequency measurement technique was introduced using the IFR 6840 microwave system analyzer. It was shown how this instrument can be used to measure the output level and harmonics of multipliers and dividers. In this application, the instrument is faster and more convenient than using a separate signal generator and spectrum analyzer. It is also superior to using a scalar analyzer as the tuned receiver can be used to reject unwanted harmonics.