A Spread Spectrum Network Analyser

Author: Cornelis Jan Kikkert
Associate Professor
Head of Electrical and Computer Engineering
James Cook University
Townsville, Queensland, 4811
Phone 07-47814259
Fax 07-47251348
Email Keith.Kikkert@jcu.edu.au

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C. J. Kikkert

James Cook University
Electrical and Computer Engineering
Townsville, Queensland, Australia, 4811
Email: Keith.Kikkert@jcu.edu.au

ABSTRACT

The paper describes the realisation of a Spread Spectrum Network Analyser using appropriate software to control a PC interface card, like a soundcard. The software generates a digitised time waveform consisting of a Spread Spectrum signal containing a number of equal amplitude spectral components. The interface card converts this waveform to an analogue signal, which is then passed through the network to be measured and then digitised using the same interface card. The difference between the sent and received spectra is the transfer function of the network and is analysed in both amplitude and phase. This Spread Spectrum Network Analyser is significantly faster than conventional Network Analysers, but suffers from dynamic range limitations. Techniques for increasing the dynamic range are discussed in this paper.

1. INTRODUCTION

In a conventional Network Analyser, a series of sine waves are generated and passed one at a time though a network under test. After the transients have settled down, the amplitude and phase of each sine-wave at the output of the network under test is compared with the amplitude and phase of the generated sine-wave and the difference is the transfer function of the network at those specified frequencies. The disadvantage of this measurement technique is that it is very slow. In many applications, such as the tuning of filters, the measured response should be very quick to provide operator feedback.

This paper proposes a different implementation for the Network Analyser, where the whole transfer function can be calculated in one measurement. The block diagram of the system is shown in Figure 1. There are several ways for implementing the required hardware. A full duplex computer sound card can be used for an audio network analyser using these techniques. A standard DSP development board available from most DSP chip manufacturers can be used. These boards normally include an audio codec. In this paper the technique is illustrated by using an Analogue to Digital Converter (ADC), Digital to Analogue Converter (DAC) and a high-speed interface card capable of operating at sampling frequencies of 40 MSPS, thus giving a Spread Spectrum Network Analyser capable of analysing signals up to 18 MHz.

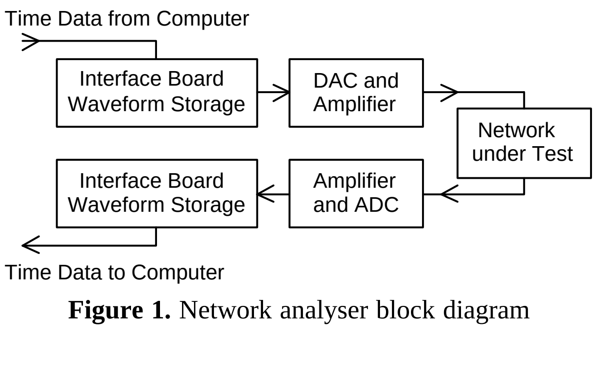

Figure 1. Network analyser block diagram

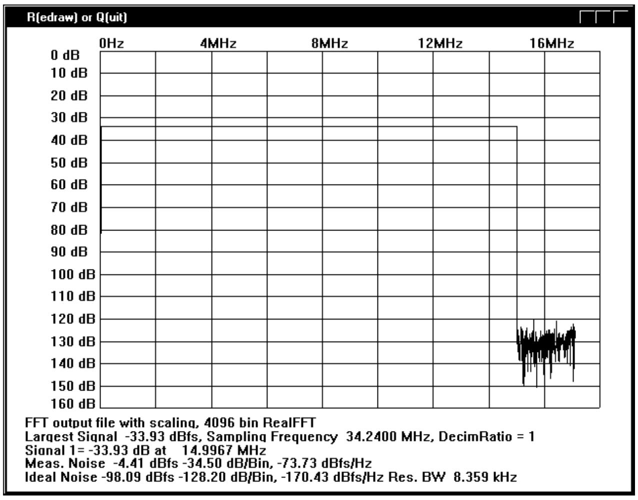

Figure 2. Generated Spread Spectrum Signal

The computer generates a time waveform, which contains a constant amplitude spectrum as is shown in Figure 2. The frequency components above 15 MHz are deliberately set to zero, to enable the dynamic range to be calculated. The phase of each of the spectral components is selected such that the ratio of the peak amplitude to the RMS amplitude is minimised [1], thus allowing the maximum signal power to be sent through the network, by varying the phase angles according to:

$$\theta_k = \frac{(k-1)(k-2)}{(N-1)} \qquad \text{Eqn. 1}$$

The resulting waveform has a peak to average power ratio (PAPR) of less than 3 dB. Typically the difference is 2.6 dB.

In order to ensure that the waveforms are steady state and repetitive over the measurement interval, so that Fourier Transformations can be applied to the waveforms, the transmitted waveform is repeated and the first few sequences are discarded. A Fast Fourier Transform (FFT) is applied to the received time samples. The difference in the magnitude and phase, of the transmitted and received spectra is the transfer function of the Network under test.

2. PROPERTIES OF THE SYSTEM

The advantage of this technique is that the transfer function of the whole network can be calculated by doing one FFT. The disadvantage of this technique is that the dynamic range is related to the sampling frequency, the range of measurement frequencies and the number of bits in the ADC and the DAC in Figure 1.

Under optimum operating conditions, the dynamic range is close to 3 dB less than the quantisation noise level of the ADC or DAC. The 3 dB being due to the Peak to Average Power Ratio (PAPR). In addition a practical ADC will have a dynamic range that is less than that of an ideal ADC, due to noise limitations in the ADC. For the AD9050 ADC used in the subsequent measurements, the dynamic range reduction is close to 3 dB. Furthermore in order to prevent the ADC overloading, the peak signal should be kept 1 dB below the maximum possible value. The dynamic range for a 10 bit ADC will thus be:

$$(1.76+6.02*10) -3 -3 -1 = 54.96 \text{ dB} \qquad \text{Eqn. 2}$$

This dynamic range is far worse than that of a conventional Network Analyser. The speed of response is however a few orders of magnitude faster.

Since a 16 bit DAC and a 10 or 12 bit ADC operating at 40MSPS are readily available, the dynamic range will primarily be determined by the ADC. Since increasing the FFT length also increases the number of carriers generated, the dynamic range is not affected by FFT length.

The dynamic range can however be increased, by generating a reduced number of spectral components. A 4096 bin FFT permits 2048 positive frequency carriers. If only 205 carriers are generated, the amplitudes of each of the carriers can be increased by 10dB without causing an overload, thereby increasing the dynamic range by 10 dB. If only four carriers are transmitted, the amplitude of each of those carriers can be increased by 27 dB, increasing the dynamic range by that amount. If only one carrier is used the amplitude of that carrier can be the full amplitude and the system corresponds to a conventional network analyser.

For a 10 bit ADC and 4096 bin FFT the ideal quantisation noise is –92 dB per bin, so that a 92 dB dynamic range can be obtained by making 2048 different measurements using one carrier for each measurement. By using a longer FFT an even bigger dynamic range can be obtained.

It is not always necessary to have a large dynamic range. When the network to be measured has a small attenuation, a small dynamic range is required. An example of this is the alignment of the pass-band frequency response of filters. Often the filters need to be adjusted to obtain a flat group delay. The conventional network analyser is normally too slow for this to be done with sufficient speed and accuracy. The proposed technique is very suitable in that it provides a real time response with good accuracy.

2.1 Speed-Dynamic range trade-off.

Having many carriers will thus provide a fast measurement of a limited dynamic range and having one carrier will provide a high dynamic range at a low speed. For many networks, both a small and a large dynamic range are required in the same set of measurements. The dynamic range can automatically be adjusted as the measurements proceed, using the following procedure:

1. A spread spectrum signal covering say 90% of the available spectrum is generated. Such a spectrum is shown in Figure 2. The 10%, of the spectrum without signals, is useful to determine the level of quantisation noise in the system and any spectral leakage due to non-linearity of the hardware or the network under test.
2. The peak input amplitude is measured and the gain of the transmitted and or received signal are adjusted to ensure that the peak signal amplitude is slightly below the peak ADC input amplitude. The spread spectrum signal is now resent and measured. The dynamic range of the measured signals should now be close to that of Equation 2.
3. Any received frequency components, which are within 10 to 15 dB of the quantisation noise per bin are subject to error and should be remeasured with an increased dynamic range by sending spread spectrum signals containing less carriers.
4. The process of 3 above is repeated and the number of carriers sent is reduced each time, until either the desired dynamic range is obtained or only one carrier is sent, which then corresponds to the maximum dynamic range.

The above technique uses one measurement with many carriers, where possible and many measurements with a few carriers, where needed. This technique is thus optimum in that it will provide an accurate measurement in the shortest time.

3. HARDWARE MEASUREMENTS

This process is best illustrated with the aid of some actual measurements. Figure 3 shows the received spectrum after the spectrum in Figure 2, containing 1794 carriers is passed through a 10.7 MHz IF filter. This filter is typical of the filters used in FM radios. The pass-band around 10.7 MHz and the spurious responses around 5 MHz, 9 MHz and 14.5 MHz can clearly be seen.

Normally the behaviour of the filter around its centre frequency needs to be known in detail. That portion of the spectrum can be investigated by generating 200 carriers covering 1.677 MHz centred at 10.7 MHz. This results in a 9.53 dB improvement in dynamic range. The spectrum using these 200 carriers is shown in Figure 4. For clarity the generated spectrum is included. The transmitted signal and received signal measurements are both done using amplifier gains which result in the full range of the ADC being used. The same gain settings are used for all transmitted measurements and for all received signal measurements.

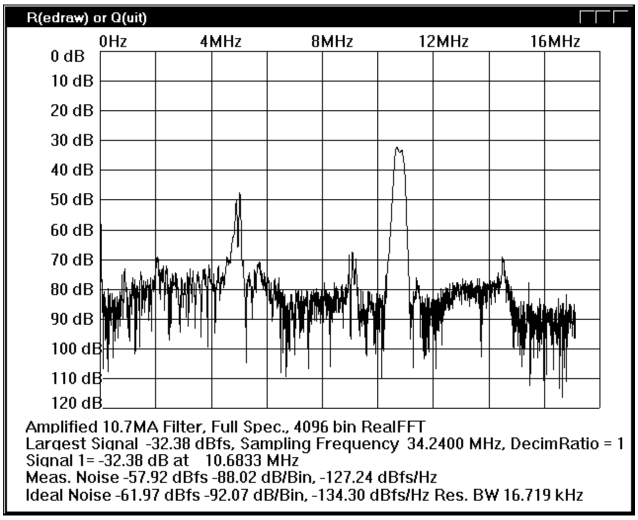

Figure 3. IF Filter Received Spectrum.

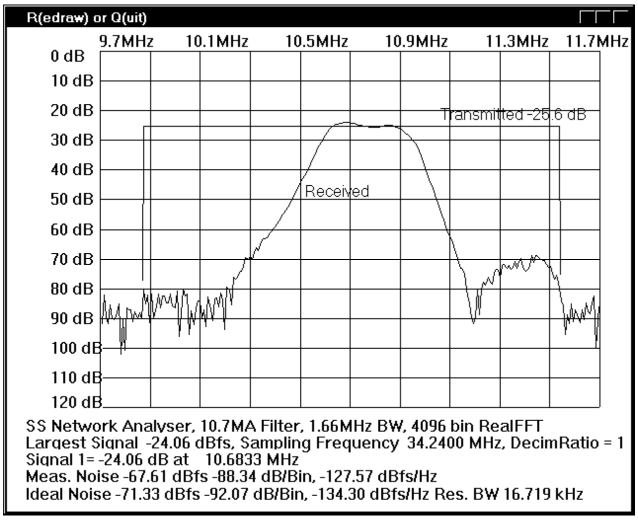

Figure 4. Spectrum for 200 Carriers.

Since the Network analyser software knows the number of bits used in the ADC it also knows the resulting quantisation noise level. This noise level can also be measured by calculating the noise spectral density in the region where no carriers were transmitted. When the measured response is too close to the quantisation noise level, the measured response will be affected by this noise. To improve the accuracy, the number of carriers can automatically be adjusted to increase the dynamic range for the required range of frequencies as outlined in section 2.1.

To increase the dynamic range by 10 dB, a series of measurements using 20 carriers are used for frequencies below 10.3 MHz and above 11.1 MHz. One such measured spectrum is shown in Figure 5, which also includes the transmitted spectrum. Note that the amplitude of the carriers are now –15.7 dB compared with the -25.6 dB carriers in Figure 3. Using only 2 carriers increases the dynamic range by a further 10 dB and using only one carrier increases it by a further 6 dB.

The amplitudes of the received signals in figure 5 are small since this corresponds to signals with a large attenuation. It is thus possible to further increase the dynamic range by

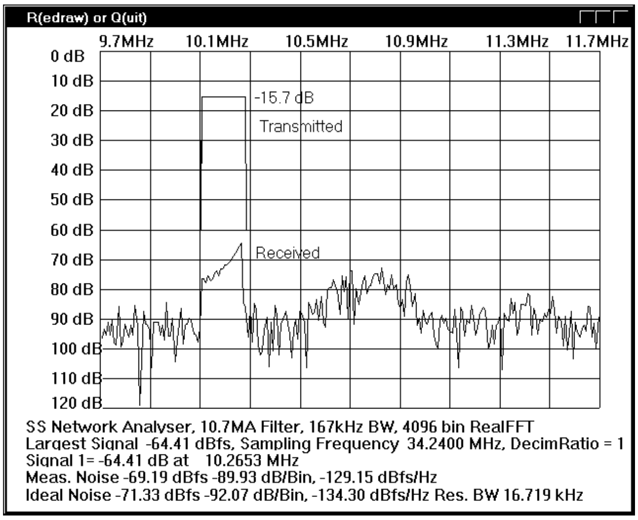

Figure 5. Received Spectrum 20 Carriers.

providing a known amount of analogue gain in the signal path, either just before the network to be measured or immediately after it.

If required a very small number of carriers like one or two can be used to further increase the accuracy of those parts of the spectrum where this is needed. By selecting the parts of the spectrum with the highest accuracy from a succession of these received spectra, like figure 4 and 5, and allowing for the appropriate amplitude correction factors, a more accurate transfer function of the filter can be obtained. Such a resulting spectrum is shown in Figure 6. This plot only combines spectra with 200 carriers, as shown in figure 4, and spectra with 20 carriers like figure 5. The improved dynamic range compared with Figure 4 can clearly be seen.

The quantisation noise level is at –102 dB per bin and the maximum amplitude is at –24 dB, so that a close to 80 dB dynamic range is obtained, even with the 10 bit ADCs used for carrying out these measurements. The results presented here only show the amplitude of the filter transfer function. The phase and group delay can be determined by comparing the phase differences between the transmitted and received carriers. Since the whole filter measurement is done at one

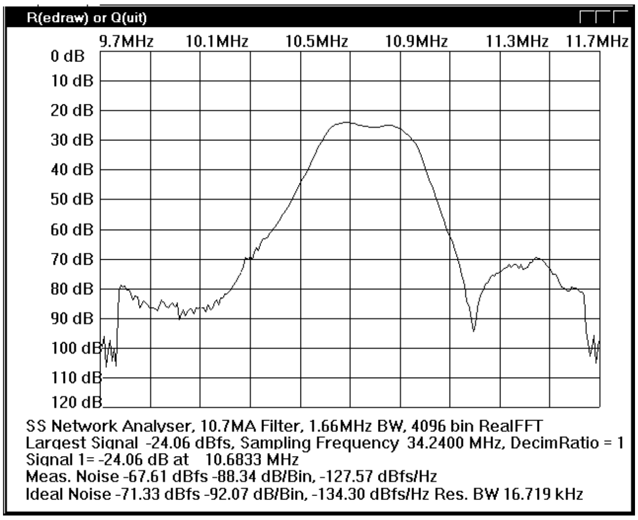

Figure 6. Combined Filter Transfer Function.

time, this type of network analyser is thus very good for measuring group delay.

4. SPARSE CARRIERS

In the Figures above, the carriers are all in adjacent bins. There is nothing to stop the number of carriers being reduced by having vacant bins between the carriers as shown in Figure 7, where one carrier in 10 is generated. A closeup of this spectrum is shown in Figure 8. That spectrum will still cover the whole useful filter band, but only provides measurements at a sparse interval. The transfer function is then obtained by interpolation between the measured points. This type of carrier generation is useful for networks where there are no steep slopes in the transfer function. Again if the Network analyser software detects a steep slope, a set of closely spaced carriers can be generated to measure the response in that region in detail. The sparse carrier waveforms have the following advantages:

1 A bigger dynamic range is obtained. By comparing figure 7 and figure 2, it can be seen that having one carrier in 10 allows the carrier amplitude to be increased by 10 dB, thereby increasing the dynamic range by 10 dB.

2 Both the frequency response of the network under test and the dynamic range of the measurements are evaluated for all frequencies of interest. The frequency response of the network under test is measured using the generated carriers and the dynamic range by measuring the quantisation noise in between the generated carriers, shown in figure 8. Both these measurements are important for verification of the measurement accuracy.

3 The accuracy can simply be increased by keeping the same number of carriers and carrier spacing but increasing the FFT length, thereby increasing the number of zero amplitude carriers.

Figure 9 shows the time waveform for the sparse carrier signal of figures 7 and 8. The time waveform is similar to the waveforms used throughout this paper, however because of the shorter repetition time, the wave-shape can easily be seen. As expected the waveform has some resemblance to a frequency sweep obtained by frequency modulation.

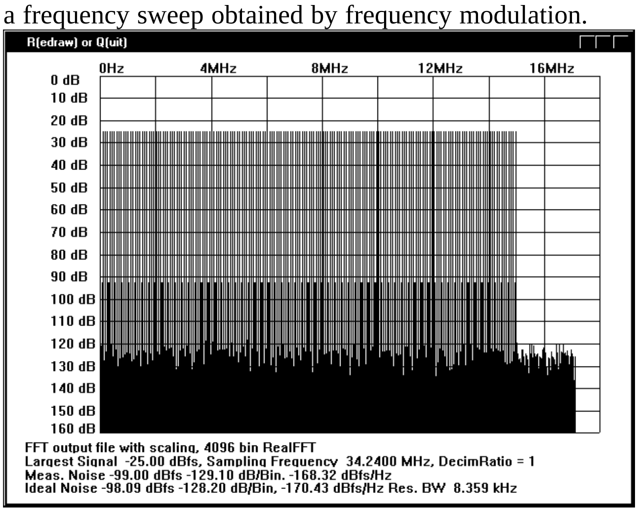

Figure 7. Spectrum for Sparse Carriers

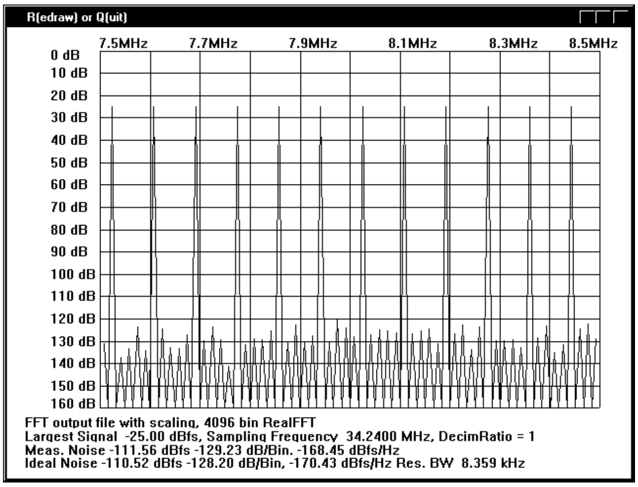

Figure 7. Close-up of Spectrum for Sparse Carriers

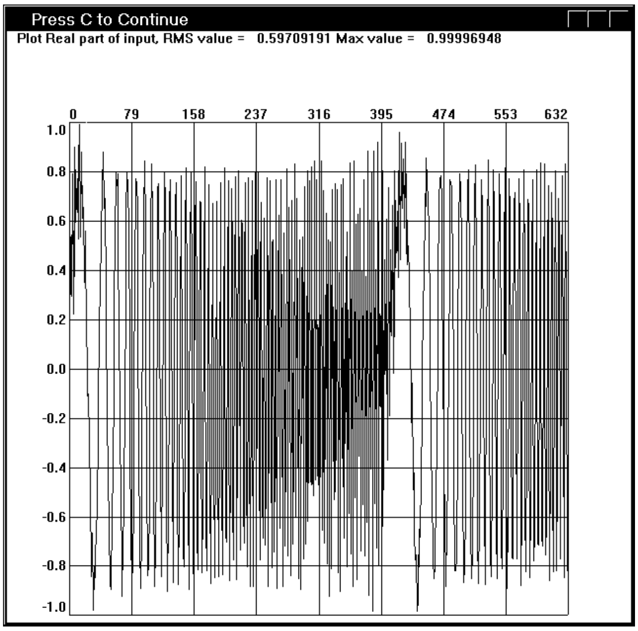

Figure 9. Time Waveform for Sparse Carriers

5. CONCLUSION

A Spread Sectrum Network Analyser has been presented, where a number of equal amplitue carriers are passed through the network to be tested. By adapting the number of carriers that are sent, the fastest possible measurement of a network to be tested can be made. Since the phase response of the network is obtained by one measurement, this technique is ideal for measuring the group delay of filters. The use of sparse carriers or a spectral region where no carriers are transmitted, allows the dynamic range of the analyser to be determined on line. The technique can be implemented using a computer soundcard, a DSP board or a high speed intreface card, ADC and DAC.

6. REFERENCES

[1] Narahashi S. and T. Nojima "New Phasing scheme of N-multiple carriers for reducing peak-to-average power ratios", Electronics Letters, Vol 30, No 17, 18 Aug 94, pp1382, 1383