A Digital Heterodyne 2-150 kHz Measurement Method

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***Abstract* — This paper describes a new method for measurements of signals in the 2–150 kHz frequency range, as required to support the regulation of conducted emissions on the power grid. The digital method is based on heterodyning, decimation and multi resolution analysis.**

***Index Terms* — Digital Filters, digital signal processing, electromagnetic compatibility and interference, power quality, quadrature amplitude modulation.**

I. Introduction

The measurement of signals in the 2-150 kHz range has become important due to the build-up of emissions on the power grid caused by power convertors such as those used in distributed generation [1]. Radio standard CISPR16-1 [2] specifies a spectral sweep method using an analogue tuned receiver. An equivalent real-time digital method is required that can be used in power quality instrumentation such that 2-150 kHz conducted emissions on the grid can be accurately measured and regulated. This paper describes a proposed method based on a digital super heterodyne.

II. Description of the Measurement Method

The proposed digital method is based on three signal processing methods, namely heterodyning, multi-resolution analysis and decimation.

A. Heterodyning

Heterodyning [3] as used in analogue or digital radio receivers, takes a frequency band centred on a given frequency and shifts it to a new centre frequency using a multiplying mixer with an oscillator frequency (f_h). This creates two new signals at the sum and difference of the two frequencies. As seen in Fig.1, to select a bandwidth f_b centred on f_h, the oscillator frequency is set to f_h, and the resulting difference frequency will be centred on 0 Hz, A low-pass filter (LPF) can then be used to select the required bandwidth f_b. For example, to measure all the frequency components between 2 kHz and 2.2 kHz, f_h would be set to 2.1 kHz and the bandwidth of the LPF would be set to 100 Hz. The resulting heterodyned band centred around 0 Hz between -100 Hz and +100 Hz would remain and all other frequencies, including the sum, will be attenuated by the LPF. F_s in Fig.1, is the sampling frequency of the analogue to digital converter (ADC) and “images” produced by the heterodyne process are also attenuated by the LPF.

In the context of this application, multiple heterodynes could be used with different f_h mixer frequencies, to shift each frequency band of interest in the 2-150 kHz band down to 0 Hz. To use heterodynes to divide 2-150 kHz into 200 Hz wide bands, would require 741 heterodynes with associated LPFs.

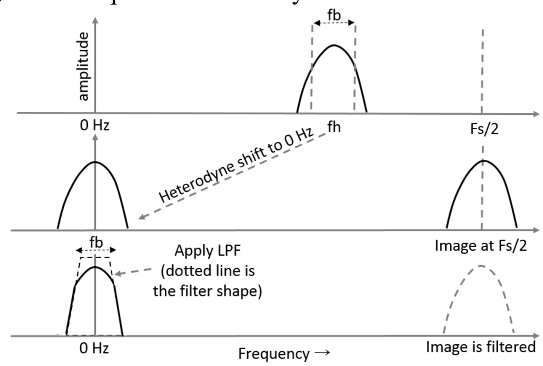

Fig. 1 Heterodyne spectrum with a band shift to 0 Hz and filtering.

The accuracy of the method is determined by the LPF cut-off which should be as sharp as possible, implying a high-order LPF. The digital LPF processes data at a rate of at least 2 times 150 kHz, which requires considerable processing and real-time measurement is unlikely to be feasible with multiple LPFs.

B. Multi-Resolution Analysis (MRA)

MRA [4] was devised for use with wavelets and is effectively a hierarchy of bandpass filters that break the measurement spectrum into a tree structure, dividing the bandwidth at each level of the tree. The MRA divided spectrum is shown in Fig. 2.

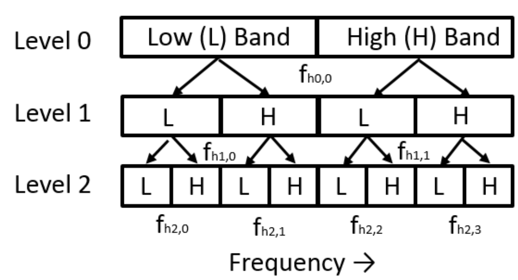

Fig. 2 MRA Tree progressively dividing the frequency band at each level. $f_{hl,b}$ are the heterodyne frequencies used at each level and band.

MRA analysis using wavelets has been applied to 2-150 kHz measurements in [5], in a similar way heterodynes can use a classical LPF at each level to perform the MRA.

C. Decimation

The LPF processing speed can be improved by reducing the sample rate, but this is not allowed under the Nyquist restrictions. However, after the LPF, the signal bandwidth is

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reduced and down-sampling can be used to reduce the computational burden of subsequent MRA levels (there are less samples to process) and also allows the low pass filter specification to be relaxed at lower levels. This classical multi-rate signal processing approach can give a significant processing speed advantage in this application.

D. Heterodyne based MRA measurement method

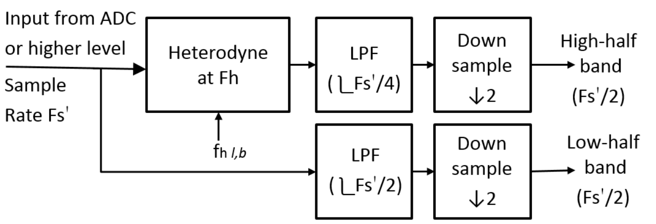

Fig. 3 One modular element of the MRA method applied at frequency $f_{h\ l,b}$. Input is a sampled waveform at sample rate Fs'; output is high and low band-limited sampled waveforms at Fs'/2.

Fig.3 shows how each element of the low and high pass operation can be achieved with a heterodyne and LPFs. This MRA modular element takes input samples (at F_s' sampling rate) and splits the bandwidth into low and high parts, outputting two sample sequences at half the sampling rate of the input. These MRA elements are identical for the whole processing tree, including the filter break points. The modular nature is convenient as the designer can concentrate effort into optimising the accuracy vs. computational speed of the module.

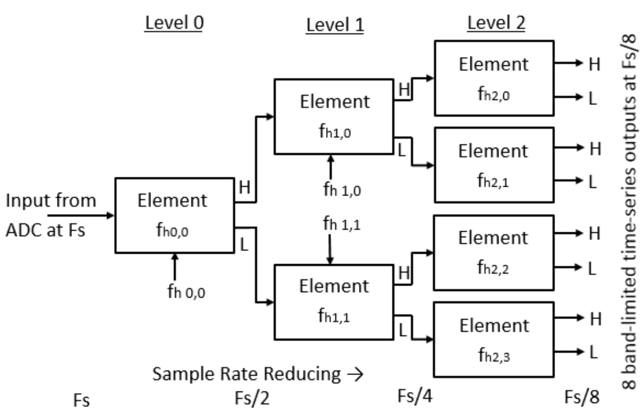

Fig. 4 Illustrative 3-level MRA using the connected modular elements shown in Fig. 3.

The MRA elements are connected together as shown in Fig.4. In this illustrative example with three levels, the spectrum is split into eight bands at the output of level 2. Note that the sampling rate is halved after each level, so although the number of elements doubles at each level, the amount of data that needs to be processed by each MRA element halves. The frequency response of the MRA method is shown in Fig.5 which plots amplitude response against frequency for each level. At level 0 in Fig.5, the high and the low band output response can be seen with the transition at half way at Fs/4 where the upper band is limited to Fs/2 as seen on the x-axis. The output at level 2, gives the signal split into 8 bands for post processing and display.

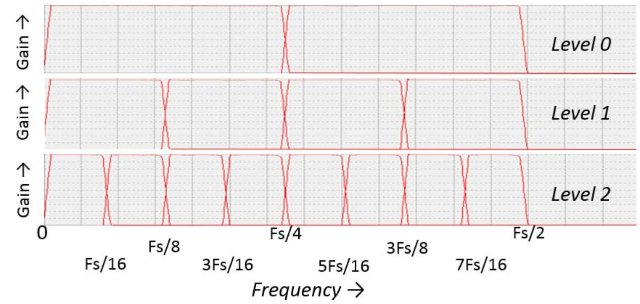

Fig. 5 Resulting frequency bands from 3 level MRA scheme.

Fig.5 show the frequency bands when implementing the method using LPFs of order 20. It can be seen that there are gaps at the band transitions which are due to the LPF not having a perfectly sharp cut-off. So any frequency component that falls in these gaps will be measured with an error. This transition error is also common to the wavelet MRA scheme.

To avoid the gaps, overlapping frequency bands for each transition can be added as an extra horizontal branch in Fig.3; this will be described at the conference.

III. Conclusion

A heterodyne based algorithm, formed by a connected structure of a single modular element is described. The modular structure is convenient to be optimised for accuracy versus processing speed. The method provides a continuous output which is ideal for measuring non-stationary waveforms and it can be made digitally equivalent to the analogue receiver specified in CISPR 16-1 [2].

Algorithm efficiency optimisations, processing speed, accuracy, output processing and implementation details for a 2-150 kHz version, together with test results will be described at the conference.

Acknowledgement

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