Hilbert-Transform-Derived Relative Group Delay Measurement Of Frequency Conversion Systems

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Abstract

A robust algorithm based on a form of the Hilbert transform has previously been shown to enable measurement based estimation of the group delay ripple of a broad group of passive circuit types. In this work it is tested on an active frequency conversion system. The results show good agreement with expected results for a down conversion system and also for measured results for a up and down conversion path through a complete microwave system. The technique is currently being implemented in a commercial scalar network analyser providing speed and cost benefits to the user.

1 Introduction

The use of the Hilbert Transform to derive phase or group delay information from the magnitude of the transfer function of a minimum phase system has been well documented [1, 2, 3]. It has been recently demonstrated that this transform can be applied to a broad class of microwave sub-systems using a standard scalar network analyser (SNA) to extract a circuit parameter which is closely related to the group delay of the circuit [4]. This new parameter is known as the *Hilbert-Transform-Derived Relative Group Delay* (HGD) and is approximately the group delay of the network minus a constant.

This paper addresses the issue of applicability of this technique to active frequency conversion systems. The basic hypothesis is that the shape of the magnitude of the transfer function and the associated group delay response of such a system are dominated by the characteristics of the band limiting element within that system (the channelisation filter for example). Therefore, if the HGD technique can be applied to that element, then it can be applied to the entire system. Since the measurement of the scalar transfer function of a frequency translation device is considerably less complex than vectorial measurements, or direct group delay measurement, this technique will enable such measurements to be made using low cost, commonly available test equipment.

2 Theory

The technique outlined in [4] requires a conventional PC and a SNA with no additional hardware. The core algorithm is currently being implemented in a commercial SNA from Wiltron Measurements Limited which will use the onboard computer to perform the numerical manipulation. The core of the algorithm is based on a

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common form of the Hilbert transform [2] given by :-

$$\phi(\omega) = \frac{-1}{\pi} \int_{-\infty}^{\infty} \frac{M(\xi)}{\omega - \xi} d\xi \qquad (1)$$

where $M(\omega) = ln|H(\omega)|$, and $H(\omega)$ is the linear magnitude of the transfer function. This is interpreted as a convolution and solved using fast Fourier transforms to give a new phase function :-

$$\phi_h(\omega) = IFFT\{FFT(M(\omega)) \cdot (-j \cdot sign(v))\} \qquad (2)$$

where, v is the new transform domain variable. The group delay of this phase function is then calculated by a difference technique. It has been shown that this process yields a group delay function which very closely approximates the group delay of the circuit under test offset by some constant.

This technique is believed to be applicable to any circuit which has a transfer function which can be accurately modelled by a ladder network. Since all ladder networks are *minimum phase*, the Hilbert Transfrorm of equation 1 can be used to derive the phase function from the magnitude function. The use of the FFT to perform this integration numerically using the band limited measurement data available is therefore the primary source of errors. Experimental tests have shown that, if the principal structure of the transfer function (say the pass band of a filter) is contained within the measurement band, with a sufficiently high number of frequerncy samples to track any fast variations, then the difference between the actual group delay of the circuit under test and the HGD as calaculated above will be approximately a constant across the majority of the measurement band.

3 Results

A simple down converter system was used to test the hypothesis. As shown in Fig.1, it consists of a broadband isolator, an edge coupled microstrip filter, an amplifier, a mixer, a local oscillator (1.97 GHz) and a 70 MHz band pass filter. The technique described above was applied to this system, and the HGD extracted is shown in Fig.2 with the group delay characteristics of the 70 MHz channelising filter as measured directly on an HP8510C Vector Network Analyser (VNA). As expected, the results show a nearly constant offset between the two traces.

A further experiment was devised to investigate the cause of the small deviations from a constant offset which are apparent in Fig.2. A simple broad band upconverter system was placed at the input to the downconverter, using a common LO for each. This enabled the measurement of the group delay using a VNA which is shown with the HGD for this new system in Fig.3. The assymmetry in the pass band is now apparent in both measurements, from which it has been inferred that they are caused primarily by impedance mismatch in the complete system which would not be present when the filter was tested on its own.

These deviations from ideal behaviour are difficult to predict in a production environment, which often necessitates the measurement of the performance of the complete system.

4 Limitations

The system used here contained a variety of different subsystem components, including non reciprocal and active devices. Some of these systems would have been expected to present difficulties to the HGD technique since their transfer functions are of the non-minimum phase type. The bandwidth of these components is quite broad (relative to the channelising filter), making their effect negligible over the narrow measurement band. This further supports the view that the HGD technique can be applied to many other microwave networks where the group delay ripple is of interest as the bandlimiting device usually dominates the group delay response of the system. The most obvious

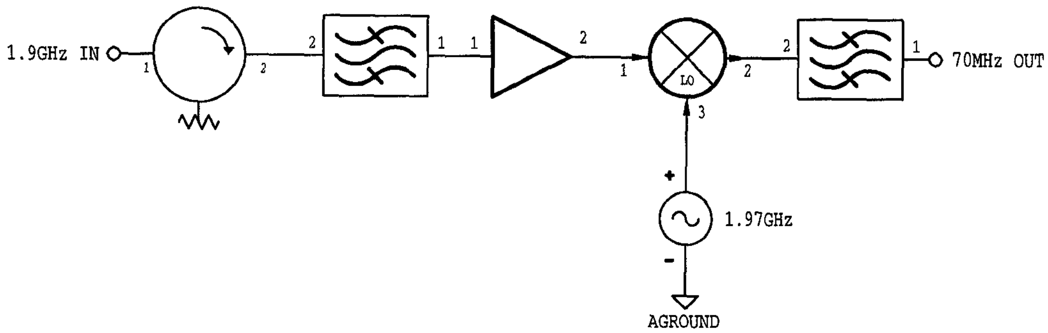

Figure 1: Block Diagram of Downconversion System

example where the technique would fail is in a system containing a narrow band delay equaliser circuit. Due to the complexity of the design technique, however, such circuits are relatively uncommon in microwave systems.

5 Conclusions

The HGD technique has been shown to work well in the measurement of group delay ripple of certain types of frequency translation devices. This will enable manufacturers of such systems to increase test throughput using relatively low cost and readily available test equipment. Such tests could also be carried out in the field by using a spectrum analyser equipped with a tracking generator and software containing the HGD algorithm.

Corollary

The use of the HGD technique to measure the group delay ripple of an entire system including frequency conversion leads to the inferrence that it could also be used for microwave link measurements. A swept source or noise source at a transmitter and a spectrum analyser equipped with software containing the above algorithm could be used to determine th group delay ripple in a microwave channel, as is currently performed using a microwave link analyser.

Acknowledgement

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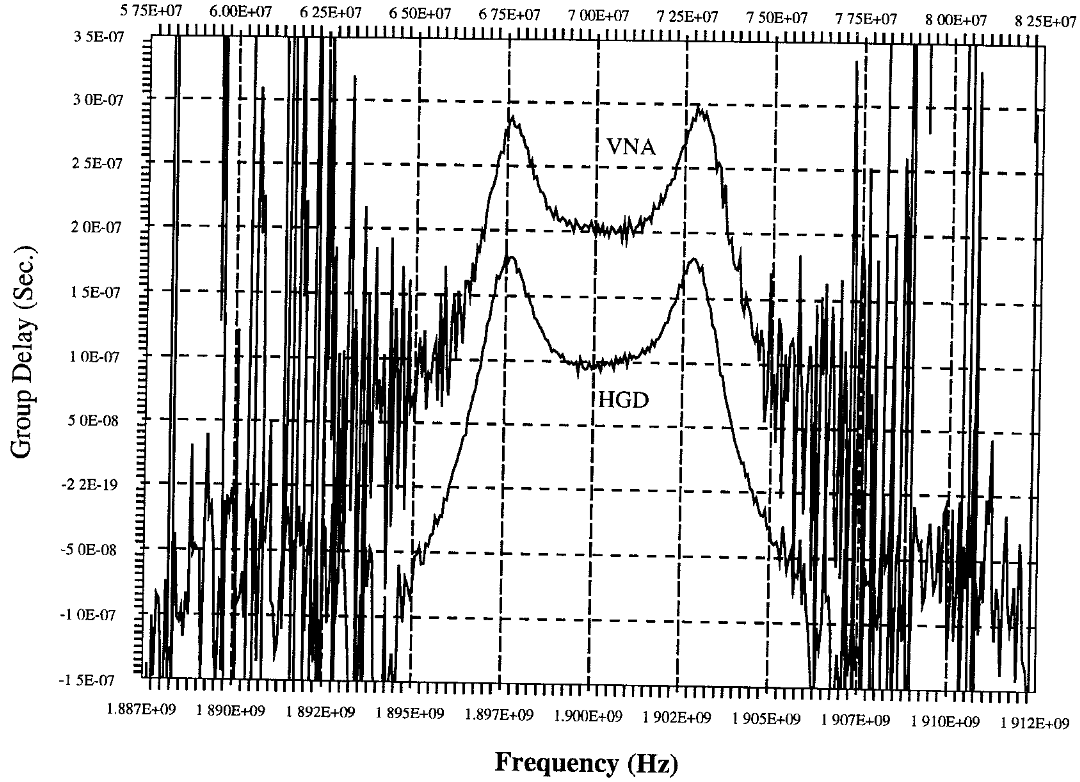

Figure 2: Group Delay of 70MHz Filter (VNA measurement) and HGD of Complete Downconversion System

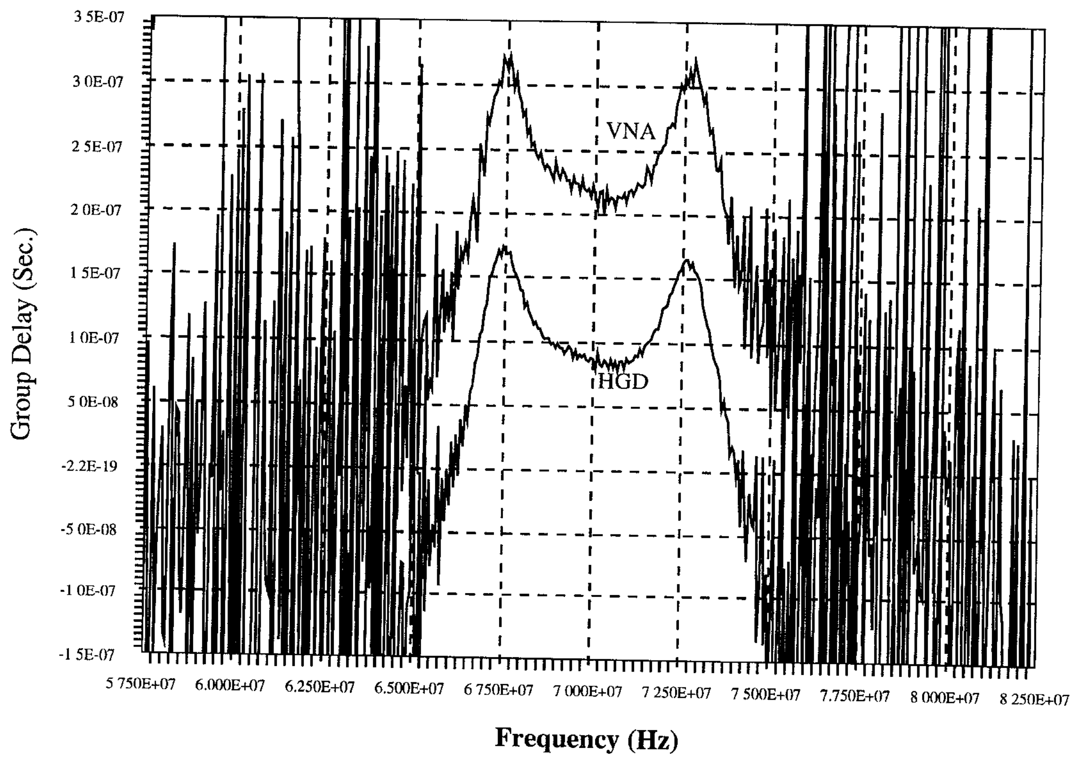

Figure 3: Group Delay (VNA measurement) and HGD of Up and Downconversion Systems