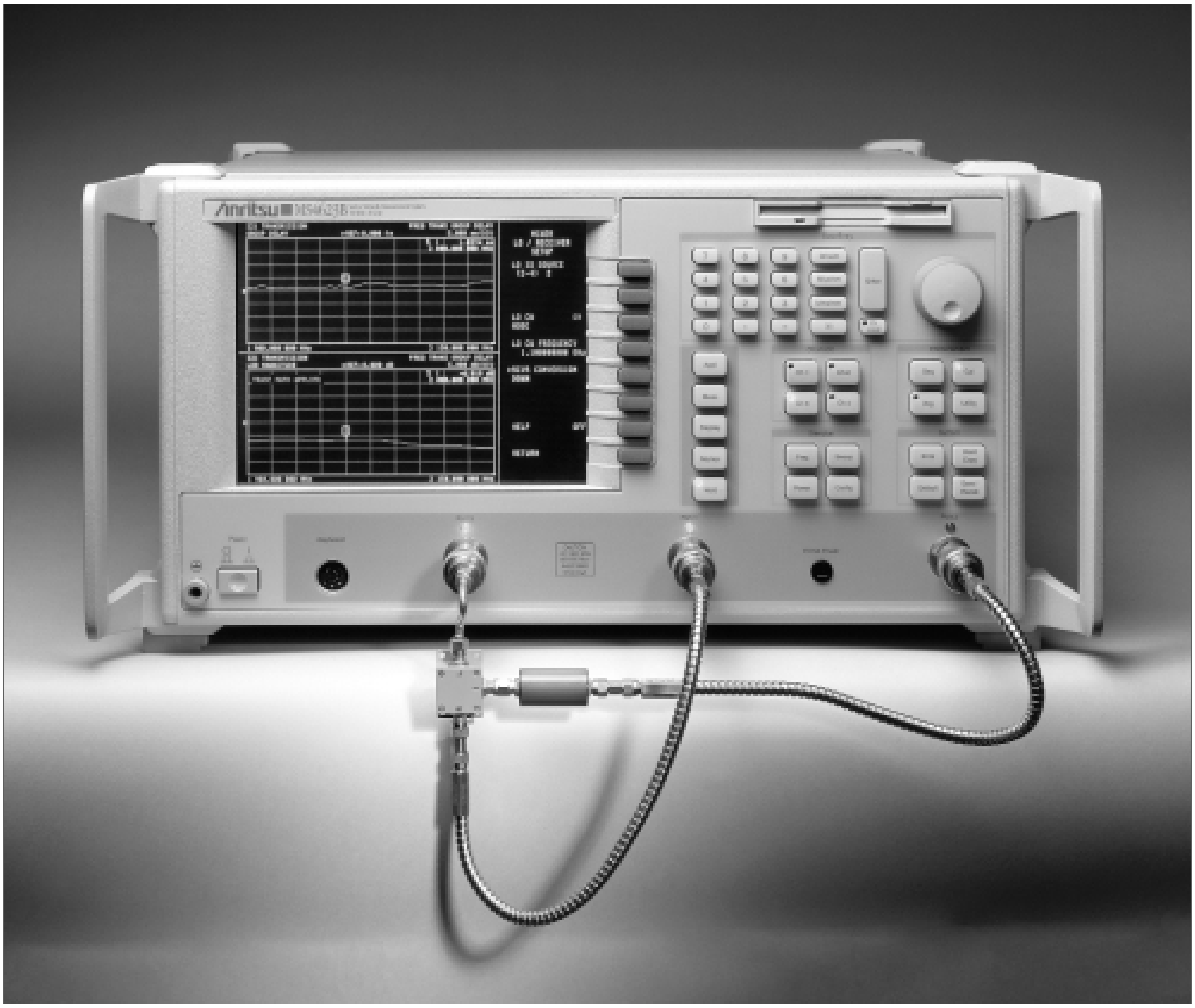
Anritsu

Frequency Translating Group Delay

Scorpion® Option 5 (FTGD)

Application Note



Group Delay Measurements of Mixers Using a Vector Network Measurement System

Linking the World

Introduction

As distortion requirements become tighter in communication systems, the specifications on group delay of constituent components and subsystems also become more stringent. While the traditional group delay graph type (proportional to $d\phi/d\omega$ where ϕ is the phase of S21 in a transmission measurement) is applicable for many measurements, it fails for frequency translating devices since accurate and stable phase information is not easily available in these generally unratioed measurements. One possibility is to place another mixer in the reference path but this generates only data relative to a given (potentially drifting or unflat) mixer and adds to measurement complexity.

A technique, dating back to early microwave link analyzers, gets around these problems by modulating the main carrier and observing the phase change of the modulating signal. Since the modulating frequency in most DUTs of this type does not change, this can again be a ratioed measurement where phase data is preserved. While in principle any type of modulation can be used, most work has been limited to simple DSB-AM and FM. AM techniques are simpler but suffer from many disadvantages; mostly related to the susceptibility to non-linearities and limited dynamic range. As a result, the class of DUTs available to AM techniques and the allowed dynamic range and accuracy are quite limited. An FM approach has an obviously improved immunity to compression and other non-linearities and can handle multipliers without frequency distortion. In order to allow for a simple correlation between phase difference and group delay, the modulation must be narrowband (the modulation index $\beta <\sim 0.3$). When these conditions hold, the group delay relative to a calibration is simply given by

$$\tau_G = \frac{(\phi + k\pi) - (\phi_{cal} + k_{cal}\pi)}{\omega_m}$$

Where the k coefficients (+1, 0 or -1) are used to correct for high-side versus low-side mixing and ω_m is the modulating frequency. The phase flips are required to compensate for a phase inversion in the mixing process when the LO is higher than the RF relative to when the LO is lower than the RF. As might be expected, an additional $+k\pi$ term is required in the first parenthetical when the DUT is a mixer. In that case, it is the DUT RF and DUT LO frequencies that must be compared. Since phase range is limited a 2π radian span, the maximum group delay that can be measured is $1/fm$.

Note that the choice of modulating frequency has a very strong effect on the resolution of the measurement since the minimum resolution on the phase measurement is set largely by the A/D subsystem (assuming the rest of the system including demodulation sections are optimized).

Scorpion® Measurement Approach

The measurement process consists of generating the modulating signal, modulating the source, demodulating the received signal, and performing the phase comparison. The modulating signal is fixed at 453.125 kHz and this frequency was chosen for several reasons:

1. The modulating frequency should be sufficiently high that group delay resolution (given by minimum $\Delta\phi$ divided by the angular modulating frequency) would be less than 1 ns but not too high to block the testing of many NB DUTs, or require unrealistic internal filters.
2. The maximum group delay range before aliasing is given by $1/fm$ hence the modulating frequency should not be too large.
3. The modulating frequency should be convenient to simplify internal system design.

This 453.125 kHz is used to directly frequency modulate the source with appropriate care being taken to equalize the modulation in different bands. The resulting modulation should have a depth of 60-90 kHz and meets the narrowband requirements. When observed on a spectrum analyzer, the first sidebands are down about 20 dB from the carrier and the subsequent sidebands are much smaller.

Since there is a power-level dependence, as well as a frequency dependence of system group delay, the calibration routine performs a frequency and power sweep. Below 3 GHz, the correction is complete over the dynamic range allowing a full selection of ALC and attenuator settings as well as frequency (within the range of calibration of course). Above 3 GHz, frequency and attenuator selections are obviously still available but some care must be taken with the ALC setting due to dynamic reflection considerations. As with 12 term calibrations, the cal is strictly only valid at the ALC level used during the cal. In the case of FTGD above 3 GHz, this restriction is important and deviation will result in increased error.

A received signal strength indicator (RSSI) system is used as a means of gauging amplitude flatness. Since the RSSI measurement is not entirely power linear and already is an exponential process, some massaging and correction of this information is required before it can be presented. During the main calibration, the RSSI is linearized via instantaneous comparisons to traditional transmission/reflection measurements at the same power levels (the system switches back and forth between modes while sweeping power). Note also that the RSSI subsystem has limited dynamic range and the gain ranging is not used to extend the amplitude measurement at this time to avoid discontinuity issues. The dynamic range is limited to about 40-50 dB for the relative amplitude measurement.

Measurement Steps

1. Connect a thru line between ports 1 and 2 to perform the group delay calibration (select at least the RF frequency range). Various power levels are cycled over the frequency range selected to determine the reference phase for the system (the system MUST have a port 1 step attenuator). If measuring above 3 GHz, be sure to select the ALC level appropriate for the measurement PRIOR to the calibration. Use a narrower IFBW if reduced jitter is needed.
2. Connect the DUT and measure. If necessary, setup the mixer mode controls for the DUT. The dynamic range is limited to about 50 dB when appropriate gain ranging is invoked. Since the system only calibrates up to maximum rated power, it is advised that the DUT output be adjusted to stay within the same range to avoid extrapolation issues. Note that the dynamic range for the group delay measurement and the relative amplitude measurements are not the same due to differences in gain ranging.
3. When measuring narrowband DUTs, keep in mind the modulation frequency is ~453 kHz. Frequency resolution of group delay artifacts/features narrower than this is not possible. *If comparing to linear measurements, be sure to use equivalent apertures* either by narrowing the linear measurement aperture (usually) or invoking smoothing in the FTGD measurement.
4. Note that jitter is limited by the fundamental A/D dynamic range and the choice of modulating frequency. In present equipment, this level is about 0.2-0.4 ns peak. The calibration by default uses a 1kHz IFBW with 10 averages (for an equivalent IFBW of 100 Hz). This can be overridden for a faster cal (more jitter) or a slower cal (less jitter).

Measurement Examples

As a simple initial measurement, consider a low pass filter. While standard group delay measurement techniques are more appropriate for this DUT, it is a way of gaining some confidence in the measurement. A 1 GHz low pass filter was measured and the results are in Fig. 1. Note the 8.8 ns peak at the edge of the passband; this is consistent with results measured using linear techniques. The amplitude data was normalized with a thru line and 0 dBm port power. Since 0 dBm was the drive during measurement, this channel represents the insertion loss of the filter.

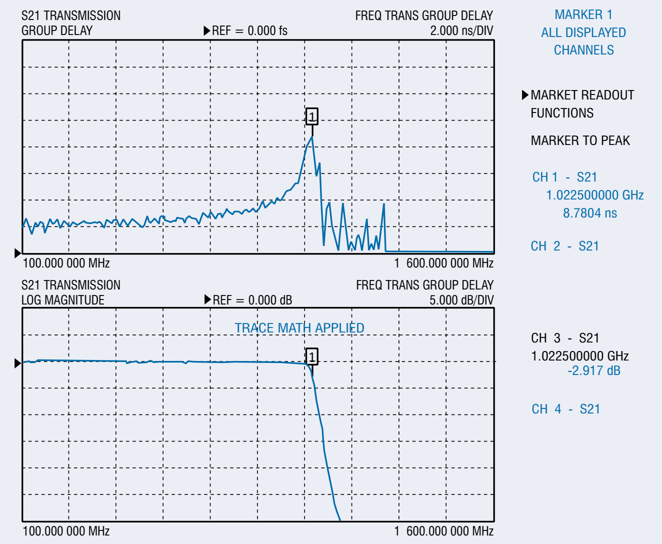
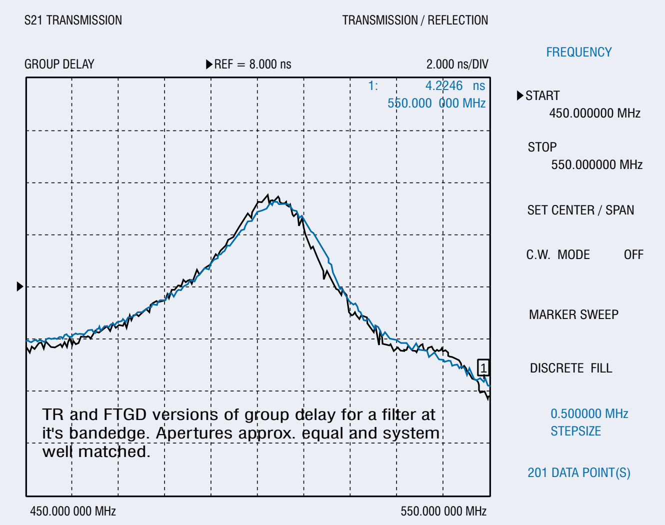


Figure 1. *A FTGD measurement of a simple 1 GHz LPF is shown here. The peak in group delay corresponds to the edge of the passband.*

When comparing these results to linear group delay measurements, it is important to equalize the apertures. In linear group delay measurements, the differentiating frequency region can be selected as a fraction of the sweep width while in FTGD it is fixed at $2fm$. For the measurement in Fig. 1, the appropriate aperture for comparison would be 0.06%. The narrow aperture associated with this measurement will reveal much more detail than a typical linear measurement but also more jitter. An example of a more direct comparison is shown in Fig. 2. Here the sweep width was reduced so that a small enough linear group delay aperture could be invoked for a comparison. The DUT is again a low pass filter with some input padding added to remove stop band match effects. The maximum difference was less than 0.3 ns.



TR and FTGD versions of group delay for a filter at it's bandedge. Apertures approx. equal and system well matched.

Figure 2. *Linear and FT group delay measurements of a low pass filter band edge are shown here. Apertures were within a factor of 2.*

Of more interest is a frequency translating DUT. Consider an integrated mixer-LPF assembly where the filter is on the RF side of the mixer. The DUT LO will be swept for a fixed DUT IF of 100 MHz (+7 dBm LO drive for this simple doubly balanced mixer) with the RF swept from 500 to 850 MHz. The low pass filter has a corner frequency of about 700 MHz. The results are shown in Fig. 3 and again one sees the peaking associated with the filter edge. As in linear group delay, the group delay data in the stop band has little meaning since the measurement is akin to performing a derivative on low level signal.

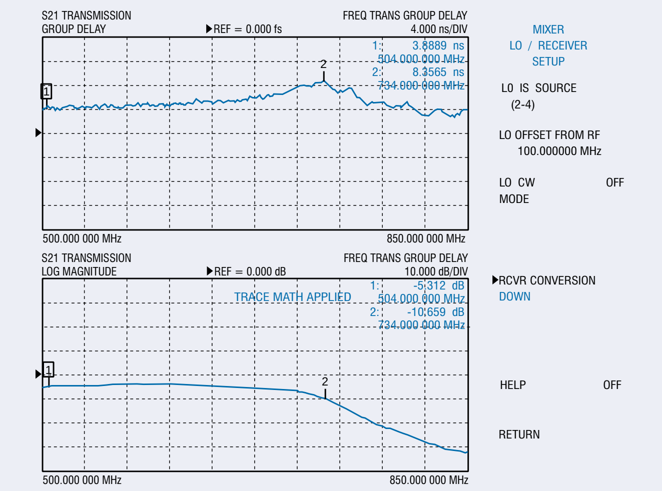


Figure 3. *Group delay and amplitude flatness of a mixer and a mixer-LPF assembly. The filter roll-off is quite evident from the amplitude display as is the passband edge peaking (marker 2) in group delay. The normalization on the amplitude display was done at the RF drive level so this channel shows filter insertion loss plus mixer conversion loss.*

The mixer conversion loss is about 5.3 dB midband as expected (from other measurements) and the maximum group delay delta is approximately 4.5 ns as may be typical for this structure. Some of the ripple in the group delay data is a result of mismatch. Note that a dynamic mismatch is of issue in any modulated network measurement since different parts of the signal will have different reflection vectors: interference between these subcomponents will produce ripple that is not observed with a single sinusoid measurement. In some sense, this makes modulated measurements more realistic assuming bandwidths are of the same order as in a practical signal.

Conclusions

This brief note has discussed the frequency translating group delay application, its uses, and the general measurement technique. The algorithm is reasonably sophisticated to allow fairly accurate, simultaneous measurements of both FTGD and relative amplitude over a wide dynamic range.

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