Swept-wavelength Amplitude and Group Delay Measurement Setup

DRAFT! (Modified: June 12, 2007)

Background: The group delay of an optical device under test (DUT) is measured by modulating an optical signal with an RF tone, e.g. at 2 GHz, transmitting it through the device, and detecting the tone with a high-speed photodetector. The detected signal is then compared to a reference path to determine the relative phase shift, given as follows:

$$\phi = \omega_{RF} \left[ \tau_{DUT} \lambda - \tau_{ref} \right]$$

Where \( \omega_{RF} = 2\pi f_{RF} \), \( \tau_{DUT} \lambda \) is the group delay of the optical path at wavelength \( \lambda \), and \( \tau_{ref} \) is a fixed (but not necessarily known) delay of the reference path. Since we don’t know the reference path length precisely, we actually measure changes in the optical path group delay as we change the optical wavelength (or frequency). An Analog Devices board (AD8302) takes the output of the photodetector and a reference RF signal as inputs and computes the relative amplitude and phase, providing these signals as voltage outputs which are subsequently digitized. The optical frequency and wavelength are related through the speed of light in vacuum “c” as follows: \( f_{opt} = c / \lambda_{opt} \) where the wavelength in vacuum is given. In an optical fiber, the wavelength and speed are reduced by the refractive index of the silica glass fiber (n~1.5), but the frequency remains unchanged.

Test Setup: The test setup consists of two major paths, an RF path and an optical path, which is shown in blue in Fig. 1. A tunable laser (Agilent 81680A) is used so that the group delay can be measured at many wavelengths.

![Test setup diagram](image-url)

Fig. 1. Test setup for optical group delay and amplitude measurement.
The RF generator (Wiltron 6637A-40) and laser are computer controlled using a National Instruments PCI-6110 (or similar) DAQ board and BNC2110 breakout box. The laser also receives GPIB commands. A trigger signal is received from the laser using the PFIO when a wavelength scan starts. From the DAQ board, analog output AO0 goes to the Wiltron FM phase lock input. The analog inputs to the DAQ board are: A10=Vphase from AD8302, A11=Vamp from AD8302, A12=Wilton FM phase lock signal (Note: in future, may be detector from interferometer output), A13=detector from gas reference. The FM output is nominally 10kHz, output sample rate 4e6 S/s, and input sampling rate 5e6 S/s (maximum setting).

The voltage outputs of the AD8302 are related to the relative amplitude of the two inputs and phase as follows:

\[ V_{\text{gain}} = 30 \text{ mV/dB} \times (\text{Power}_A - \text{Power}_B) + 900 \text{ mV} \]

\[ V_{\text{phase}} = -10 \text{ mV/degree} \times (|\phi_A - \phi_B| - 90^\circ) + 900 \text{ mV} \]

The voltage outputs of the AD8302 (see the datasheet for more details) are shown in Fig. 2. The maximum voltage range for the outputs is 0 to 1.8V. The measured relative delay is proportional to the relative RF phase. The delay, relative to the reference path, is given by

\[ \tau_{\text{ns}} = \frac{\phi_{\text{RF}} (\text{rad})}{2\pi f_{\text{RF}} \text{ GHz}}. \]

A 2\pi phase change (of the detected RF signal) implies a change in delay of one period. For a 2GHz modulation frequency, one period is 500ps. Note that the Vphase output is V-shaped, so we don’t know the exact phase unless we could limit the range to 0-180 degrees (or 180-360 degrees). To overcome this ambiguity problem, we sweep the RF frequency over at least one cycle of the phase response as indicated in Fig. 3. Ideally, the optical wavelength should not change during this RF frequency sweep. The output for one cycle is then input to the Goertzel algorithm which calculates the amplitude and phase for the fundamental frequency. We then use this information to calculate the output amplitude and delay (in ps).

Fig. 2. Response of the AD8302 amplitude and phase outputs from the data sheet.
Fig. 3. Vphase outputs from AD8302 for two different group delays as the RF source is frequency modulated.

Notes:

1. NI DAQ board in Dell Dimension 4550 is working on analog inputs and outputs; however, the DAQ board in Dell Precision 380 analog outputs are not working!
2. The DC bias to the modulator is not shown explicity in Fig. 1, nor is the possibility of adding another coupler and interferometer to track the linearity of the wavelength sweep.
3. A polarization controller (e.g. fiber paddles) is often needed directly in front of the DUT.
4. Data must be acquired at two modulation frequencies if 3rd-order dispersion is significant.

Setup and Test Procedure:

The major steps in the test algorithm are shown in Fig. 5. A picture of the optical table and equipment is shown in Fig. 6.

Latest software version: Fast_phase_Goertzel_Mathscript_newref.vi (updated ~ May’07)

The detailed procedure, including setup is described in the following steps:

1. Setup the optical modulator: The modulator has a DC bias that must be set to the 3dB point (half-maximum) value. The modulator is very polarization dependent, so one of the principal states of the modulator is first found by varying the DC bias to find a minimum transmission point, then varying the input polarization (using fiber paddles) to make the minimum as low as possible (preferably, 30dB below the maximum transmission or more). Then, the DC bias is changed to find the maximum transmission, then moved to the half-transmission (or 3dB) value. Typically, the bias is around +5.7V (channel 7 of power supply) for the current modulator in “Mike’s box”. The VOA should be grounded with -22V on equalizer.
2. The Agilent tunable laser is set to +0dBm (may need to increase power to +5.5dBm), Peak transmission is about -10dBm. The Picometrix photodetector should have the appropriate voltage applied to it with a bias T on the output (otherwise it has a 3V offset on the output). Check the trigger signal (PFIO).

3. The Wiltron RF generator may be set at +16dBm with a 90/10 splitter on the output. The 90% output goes to the optical modulator (e.g. “Mike’s box”) and the 10% goes through ~23dB of attenuation to the reference input on the AD8302. The attenuators are to match the amplitude of the reference and photodetected signals as close as possible (AD8302 Vamp~0.9V), which increases the dynamic range of the amplitude measurement. Keep the difference in endpoints of the period to within 0.015V for best accuracy of Goertzel algorithm. Check that the AO0 goes to the FM phase lock on the backplate. On the frontside, enable the FM and phaselock button. Set the frequency to 2GHz, CWF1, AM enable?

4. The AD8302 should have a 5V power input. Check the outputs: AI0=Vphase, AI1=Vamp.

5. Check connection of gas cell reference and interferometer photodetector outputs to analog inputs.

6. Run a wavelength sweep and verify that one FM cycle is being captured (use “% to shave off” to adjust), Want in the range of 0.2-0.3 or change amp voltage (~3V) to FM out.

7. Measure “gas cell” as reference device and compare to previous measurements to verify proper test set operation. ...
Fig. 4. Front panel of Labview software.
Fig. 5. Major steps in the measurement procedure using RF frequency modulation.

For additional information see:

Appendix: Mathscript

samplespercycle=round(samplespercycle);

xaxis=0:(speed*FMdt):(stopwl-startwl);
xaxis = xaxis + startwl;

deltaw=(stopwl-startwl)/outputcycles;
stepsize=deltaw;
selecting what part of cycles to pull out (5% to 95% of cycle)
periodstart=percentage*samplespercycle;
periodend=samplespercycle-(percentage*samplespercycle)-1;

periodstart=round(periodstart);
periodend=round(periodend);
samples=periodend-periodstart+1;

%----------------------
%----------------------
Make reference signal of pulling data out for plotting
triggerend=outputcycles
trigger=0;
for n=1:triggerend;
    trigger(1,(((n-1)*samplespercycle)+(periodstart)):(((n-1)*samplespercycle)+(periodend)))=1.6;
end

%----------------------
Pulling out cycles
for n=1:outputcycles;
goertzeldata(n,1:((1-2*percentage)*samplespercycle))=FMphase1,(((n-1)*samplespercycle)+(periodstart)):(((n-1)*samplespercycle)+(periodend)))
end;

%----------------------
%----------------------
Goertzel Algorithm
FMgoertzel=0;
FMgoertzelx=0;

for i=1:outputcycles
    %FMref=goertzeldata(ref,1:(samples));
    FMshifted=goertzeldata(i,1:(samples));
    x=FMshifted;
    xmean = mean(x);
    x = x-xmean;
    xmax = max(x);
    xsamps = 0: 1/length(x):1-1/length(x);
    y = xmax*cos(2*pi*xsamps + rad_shift);
    FMref = y + xmean;

down sample=50;
%y=downsample(y,down sample);
%x=downsample(x,down sample);

range=1:50;
xg = goertzel(x,range); % Now use Goertzel to obtain the PSD
yg = goertzel(y,range);

[z,yg_correct_sample]=max(yg); %Grab the sample number which is our target frequency
[z,xg_correct_sample]=max(xg); %Grab the sample number which is our target frequency
FMgoertzel(1,i)=angle(yg(1,yg_correct_sample)/xg(1,xg_correct_sample))*180/pi;  %Calculate
%actual shifted angle between signals
FMgoertzelx(1,i)=startwl+(deltaw*i)-deltaw;
end;
%-------------------------------------

if length(xaxis) ~= length(FMphase)
    xaxis = xaxis(2:length(xaxis));
end;

onecycletime=totalsamplingtime/outputcycles;

figure(1)
title('Example of Data Taken (1st few cycles)')
xlabel('Wavelength (nm)')
ylabel('Voltage (Volts)')
plot(xaxis,FMphase,xaxis,FMcontrol,xaxis(1,1:length(trigger)),trigger)
axis([ (startwl +1*stepsize) (startwl+ 11*stepsize) 0 2.5, []])

figure(2)
title('Reference Cycle Vphase Data')
xlabel('Wavelength (nm)')
ylabel('Voltage (Volts)')
plot(xaxis,FMphase,xaxis,FMcontrol,xaxis(1,1:length(trigger)),trigger)
axis([((startwl + 1*stepsize) (startwl + 2*stepsize) 0 2.5])

figure(3)
plot(xaxis,FMmagnitude)
title('Device Magnitude Performance Curve')
xlabel('Wavelength (nm)')
ylabel('Voltage (Volts)')

figure(4)
plot(FMgoertzelx,FMgoertzel*250/180)
title('Device Phase Performance Curve')
xlabel('Wavelength (nm)')
ylabel('RF Phase Delay (ps)')
axis([startwl stopwl -250 250])
save(filename,'FMgoertzel','FMmagnitude')