Application Note
VSWR Detection Using LMH2110

TEXAS INSTRUMENTS

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ABSTRACT

An impedance discontinuity between a RF transmission line and any load, such as an antenna can cause power to be reflected back into the transmission line. This leads to deterioration of the transmission line insulation, transmitter, antenna and quality of transmission. Voltage Standing Wave Ratio or VSWR, is a metric to analyze the quality of transmission & used to keep track of the competence and robustness of transmission.

This application note describes the process of measuring VSWR and demonstrates VSWR measuement with a log detector using Texas Instruments' LMH2110. A fully differential amplifier, THS4561 is used to pre-condition the output of the LMH2110 for a stand-alone ADC or integrated ADC in a microprocessor or FPGA, where the VSWR can be calculated.

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1 Introduction

The RF source, the load and transmission line in a radio system can be assumed to have a certain lumped impedance. If these two impedance are equal, all the transmitted power flows into the load. This is known as ideal matching. For example, if the line and load do not match, meaning that the signal traveling on the transmission line faces some discontinuity in impedance, a part of energy gets reflected back into the transmission line. This mismatched impedance can interfere with the signal traveling forward (from source to load) and create a *standing wave*.
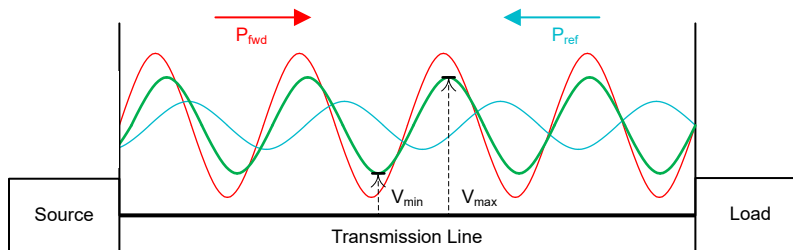

Figure 1-1. Standing Wave Generation

Standing waves are an indication of the quality of transmission. A well-matched transmission line has no reflection and thus no standing wave. The green curve in the Figure 1-1 indicates a *standing wave*. In most real-world applications, a standing wave is formed on the transmission line which can result in power losses due to heat dissipation. The reflection coefficient (Γ), is also used to denote the ratio of forward and reflected power.

$$\Gamma = \frac{P_{ref}}{P_{fwd}} \tag{1}$$

Return loss is the difference in power between the forward and reflected path, when expressed in dB

$$\Gamma = -20\log(\Gamma) \tag{2}$$

VSWR, short for Voltage Standing Wave Ratio, is the ratio of the maximum amplitude to the minimum amplitude of the standing wave.

$$VSWR = \frac{V_{max}}{V_{min}} \tag{3}$$

It is not very efficient to calculate VSWR using Equation 3 since it is not straightforward to probe V_{max} and V_{min}, we generally demonstrate VSWR as a function of the reflection coefficient as shown in Equation 3.

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{4}$$

In practical scenarios, VSWR is typically greater than one due to imperfect matching of transmission line and load. A higher VSWR portrays high reflected signal power, for example a VSWR of value 6 can mean 50% of the power transmitted forward is being reflected back. This can damage the RF signal source and cause degradation of transmission quality. It is thus necessary to keep track of VSWR to understand the reflected power strength to prevent deterioration of the source, transmission line and signal quality.

A VSWR detector is shown in this application note. Two power detectors are used to detect forward and reverse power and their output in log form is subtracted using a difference amplifier. The power values must be divided to calculate, and a log transformation of the power allows implementation of this division by simple subtraction circuits using an operational amplifier. This dual log detector outputs the reflection coefficient as a differential voltage which can be fed into an ADC on a processor or controller/FPGA, from which the value of VSWR can be computed.

2 Log Detector System

2.1 Block Diagram

The VSWR detector employs two power detectors directionally coupled to a transmission line, one coupled in a forward direction to capture forward power and another coupled in the reverse direction to capture reflected power. The outputs of the two power detectors, LMH2110 are fed into a fully-differential amplifier, THS4561 used in a difference mode to get the ratio of forward power to reflected power as a differential voltage. The THS4561 is selected because of the high bandwidth, which allows a quicker cycle time for VSWR calculation. The outputs of the THS4561 are then fed to an ADC on a FPGA or an MCU/MPU where the value of VSWR can be calculated.

The coupler that needs to be used is a directional coupler, to maintain precise power reading based on the directive and coupling factor of the coupler. A bi-directional coupler can also be used if the specifications work for the accuracy requirements.
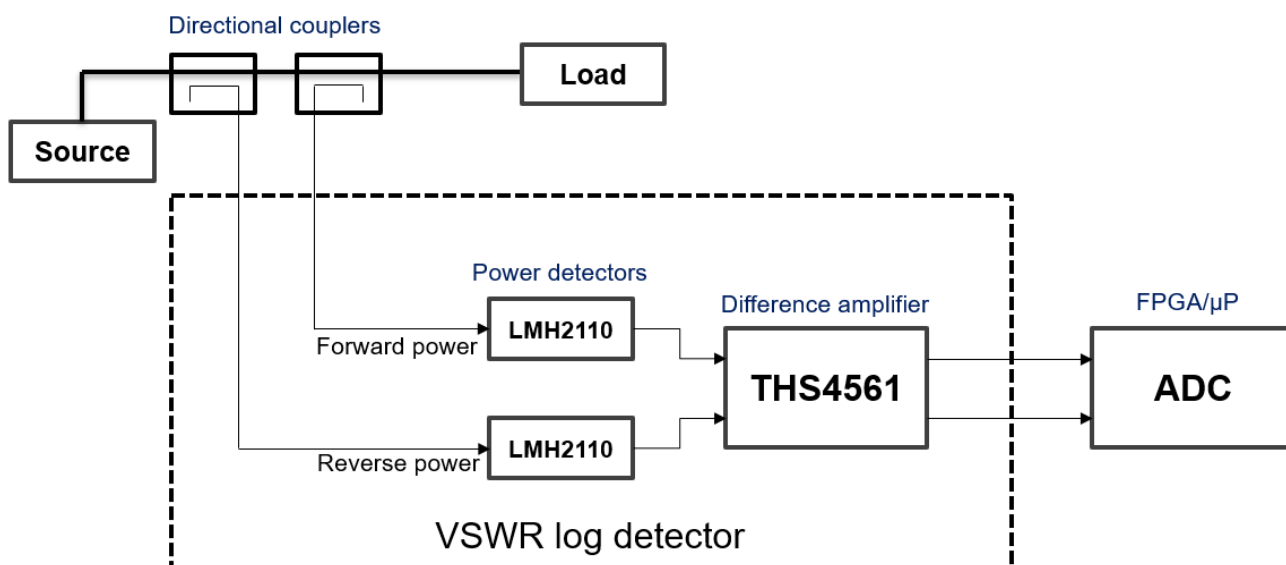

Figure 2-1. VSWR Measurement System Block Diagram

The output voltage swing of the THS4561 is an important parameter as a higher, unregulated output swing can saturate the ADC and give incorrect measurement values. THS4561, operating as a difference amplifier, has the input voltage set according to the output swing required using resistor dividers on the inputs and the gain setting of the THS4561.
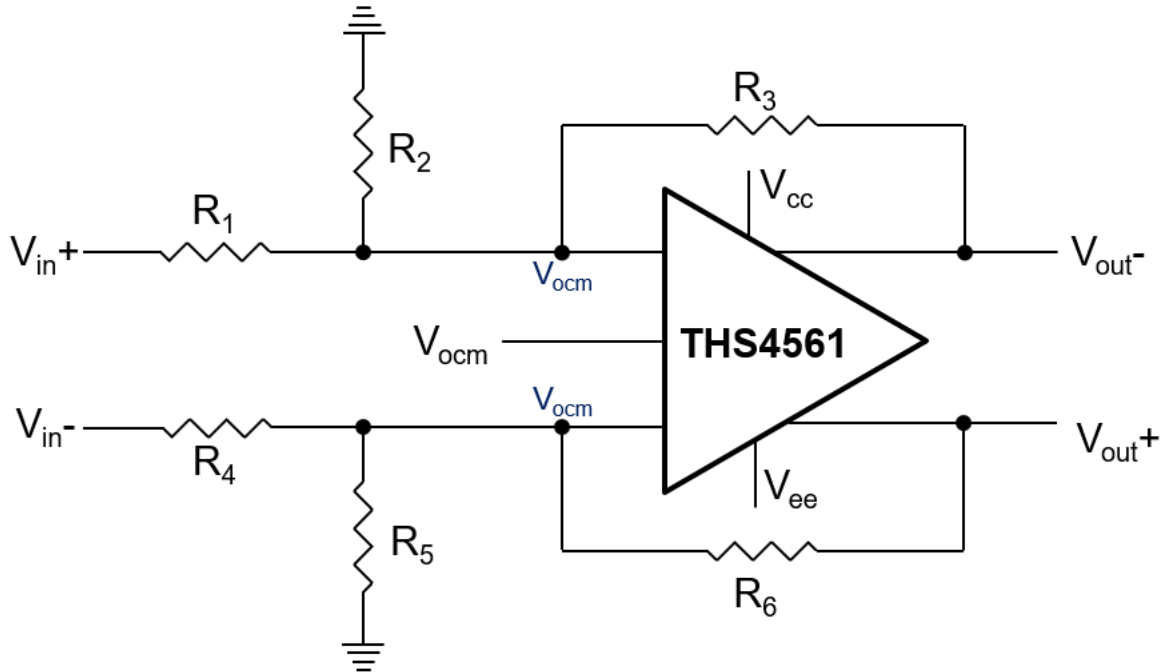
2.2 Output Swing Derivation

Figure 2-2. THW4561 Output Swing Calculation Schematic

Our specification of interest, $V_{out,p-p}$ (written as V_{opp}) is as below,

$$V_{opp} = V_{out+} - V_{out-} \tag{5}$$

Both V_{in+} and V_{in-} come from the outputs of the two power detectors, LMH2110. V_{in+} represents the output from the forward power detector, similarly V_{in-} represents the same from the reflected power detector. Their difference is V_{ipp}.

The THS4561 has an additional input, V_{ocm}, that sets the common mode voltage of the device. By default, the device is set at the mid-point of the two supplies, V_{cc} and V_{ee} for maximum differential output swing, however the device can be set by the user to control the output voltage swing.

In this example, the feedback resistor on both inputs are set to a fixed value, such as 2 kΩ. This enables easy calculation for the resistances in the divider network. The values of R_1, R_2, R_4, and R_5 can be derived for a given V_{cc}, V_{ee}, V_{ipp} and V_{ocm}, and a desired V_{opp}.

2.3 Simulation Results

In this example for the measurement of reflection coefficient required for VSWR calculation, 50 MHz transmission is assumed which is the lower transmission frequency limit for the power detector LMH2110. The LMH2110 can take a power input from the range -39 dBm to 7 dBm at a frequency of 50 MHz, for which the corresponding output voltage ranges from 0 V to 1.96 V nominally (Section 6.5 of the *LMH2110 8-GHz Logarithmic RMS Power Detector with 45-dB Dynamic Range* data sheet).

For an input of ±1.96 V (Vipp = 3.92 V), a Vocm of 1.6 V is set externally, the Vcc is set at 3.3 V. For a desired maximum output swing of ±1.8 V (Vopp = 3.6 V), we have derived the values of resistors using circuit loop equations as given in Table 2-1, and the schematic in Figure 2-2 then becomes as shown in Figure 2-3.

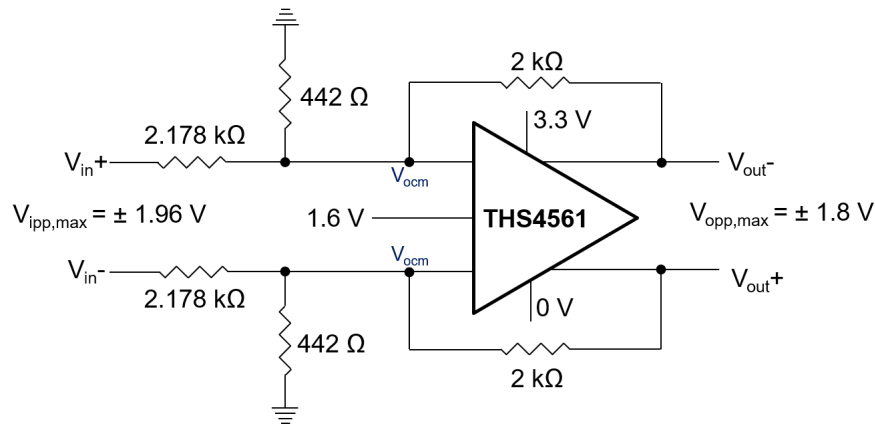**Figure 2-3. THS4561 Test Schematic**

Table 2-1. Resistor Values

Resistor	Resistance
R_1	2.178 kΩ
R_2	442 Ω
R_3	2 kΩ
R_4	2.178 kΩ
R_5	442 Ω
R_6	2 kΩ

The recommendation is for the output swing to be always set such that the ADC is not saturated under any circumstance. To have control over the output common mode voltage, the recommendation is to use a voltage reference to set a precise level at the V_{ocm} pin.

Assuming a signal on the transmission line at 50 MHz with power -10 dBm, and the reflected signal power is measured at -35 dBm. The output voltage of the LMH2110 power detectors correspondingly are 1.237 V and 0.1745 V for forward and reflected power respectively. The input and output graphs are shown in Figure 2-4.
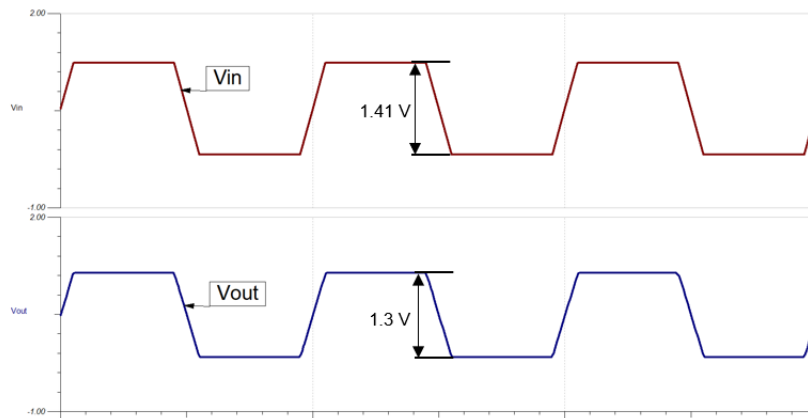

Figure 2-4. Input and Output Swing of the THS4561 for Given Test Setup

Based on observation, the input and output voltage swing follow a linear relationship for unity gain.

$$\frac{V_{in,\,p-p}}{V_{out,\,p-p}} = \frac{V_{ipp,max}}{V_{opp,max}}$$

(6)

3 Power Detector – LMH2110

3.1 Description

The LMH2110 is a 45-dB Logarithmic RMS power detector particularly designed for accurate power measurement of modulated RF signals that exhibit large peak-to-average ratios; that is, large variations of the signal envelope. The RMS measurement topology inherently makes sure a modulation insensitive measurement.

The device has an RF frequency range from 50 MHz to 8 GHz. The device provides an accurate, temperature, and supply insensitive output voltage that relates linearly to the RF input power in dBm. The LMH2110 device has excellent conformance to a logarithmic response, enabling easy integration by using slope and intercept only, reducing calibration effort significantly. The device operates with a single supply from 2.7 V to 5 V. The LMH2110 has an RF power detection range from –40 dBm to 5 dBm and is designed for use in combination with a directional coupler.
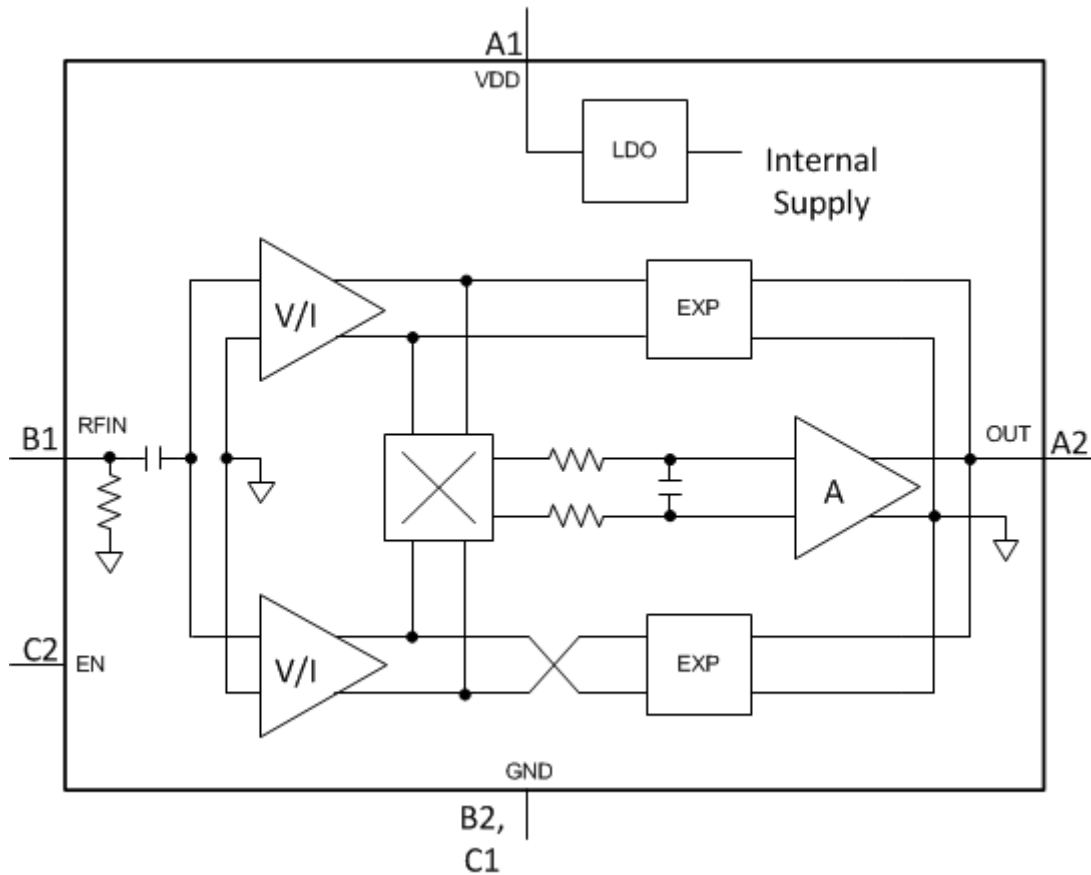
Figure 3-1. LMH2110 Functional Block Diagram

3.2 Log Conformance

To describe how close the transfer is to a logarithmic function, the log conformance error is used. To calculate the log conformance error the detector transfer function is modeled as a linear-in-dB relationship between the input power and the output voltage. Section 8.2.1.2.1.2 of the *LMH2110 8-GHz Logarithmic RMS Power Detector with 45-dB Dynamic Range* data sheet explains how the log conformance error is calculated.
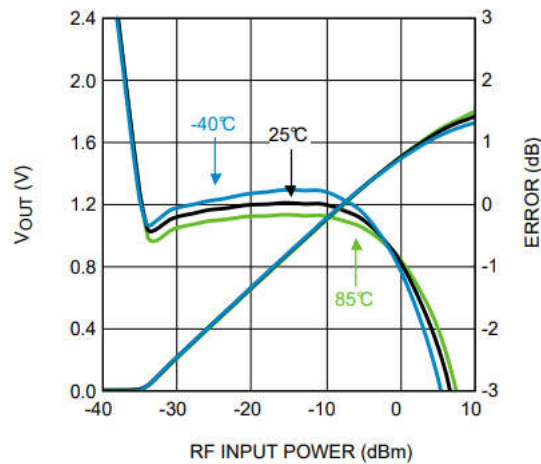
Figure 3-2. V_{OUT} and Log Conformance Error of LMH2110 Across Dynamic Range at 1900 MHz

3.3 Calibration

A number of factors affect the calibration of the power detector such as frequency, power supply, slope & intercept of the transfer function, parasitic impedance presented by the transmission line and many more parameters. Please note that the calibration needs to be done for every implementation separately due to process variations as well. As this is outside the scope of this particular application note, please reach out to TI at E2E™ design support forum for assistance with a comprehensive design.

4 Additional Approaches

4.1 External ADC Approach

If the processor does not have an ADC, or the ADC on-board is unavailable for this application, an external ADC such as the ADS7057 can be used to feed a digital signal into the processor.

4.2 Single-Ended Approach

If the processor/FPGA have only a single-channel input into the ADC, a single-ended operational amplifier such as the TLV365 can be used instead of a fully differential amplifier and the same implementation can be followed with an external single-ended ADC such as ADS7042.

5 Summary

The output of the log detector is used to calculate the VSWR by converting the differential voltage back into power as a fraction, essentially giving the return loss. In the presented example in Section 2.3 the return loss comes out to be 0.056, for which the VSWR is 1.112:1. A VSWR as close to 1 as possible demonstrates excellent matching of the load. Although this app note explains VSWR detection in detail using an external difference amplifier, we can extend this theory to other approaches as well based on the availability and nature of the ADC on the processor/FPGA.

6 References

- Texas Instruments, *LMH2110 8-GHz Logarithmic RMS Power Detector with 45-dB Dynamic Range*, data sheet.
- Texas Instruments, *THS4561 Low-Power, High Supply Range, 60-MHz, Fully Differential Amplifier*, data sheet.
- Texas Instruments, *REF35 Ultra Low-Power, High-Precision Voltage Reference*, data sheet.
- Texas Instruments, *ADS7057 14-Bit, 2.5-MSPS, Differential Input, Small-Size, Low-Power SAR ADC*, data sheet.
- Texas Instruments, *TLVx36550-MHz, Zerø-Crossover, High-CMRR, RRIO Operational Amplifiers*, data sheet.
- Texas Instruments, *ADS7042 Ultra-Low Power, Ultra-Small Size, 12-Bit, 1-MSPS, SAR ADC*, data sheet.
- Texas Instruments, *Single-Ended to Differential Signal Conversion Using an OPamp and FDA for Unipolar Signals*, analog engineer's circuit.

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