Calibration of frequency propagation channel sounder based on five-port reflectometer

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Abstract

Five-port reflectometer which consists of a ring with 5 arms (two inputs, three outputs) and three RF power detectors has been used as a vector network analyser, a demodulator in the homodyne receiver as well as in Phase Looked Loop (PLL) and so on. Calibration of five-port reflectometer is an important task. In this paper, we present a calibration method of five-port for a propagation channel sounder. The method is based on measurement of the phase differences between the three voltages at the five-port's outputs in order to determine the ratio of two input incident waves. The frequency channel sounder based on five-port is calibrated for each frequency from 2.2 GHz to 2.6 GHz with 1 MHz step. This method can also determine the absolute delays of each propagation path in the propagation channel . The calibration method is validated using measurement data.

Index terms - Five-port reflectometer, Calibration method, Multi-path delays, frequency sounding technique, channel sounder.

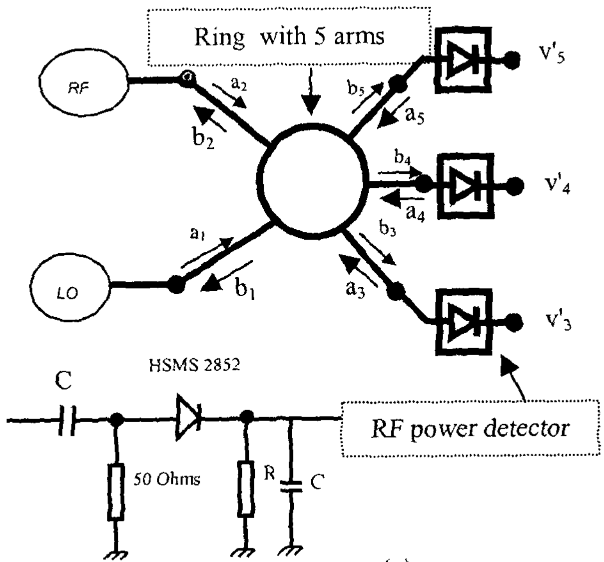
I- INTRODUCTION

In frequency channel sounder, the transfer function of the channel is measured at each frequency in the frequency band and the equivalent low pass impulse response of the channel is calculated by applying IFFT (Inverse Fast Fourier Transform) [8]. In this technique, high measurement accuracy is obtained because the source is tuned and phase locked to each frequency point. The Vector Network Analyser (VNA) is usually implemented in order to measure the transfer function of the channel . But the system is expensive, especially when the multiple VNAs are required in antenna array.

The six-port reflectometer was introduced by Engen as an alternative network analyser in the Seventies[1]. Recently, the six-port or five-port technique has been applied to many systems such as radars [2], homodyne receiver [3] and so on. Application of five-port for frequency channel sounders not only decreases the cost but can also measure the non stationary propagation channel using an antenna array [9]. Calibration of five-port reflectometer is an important task. Various methods of calibration have been developed. The method proposed in [4] is robust but it requires a lot of calculation. Another simple method was developed in [5]. However its drawback is the limitation of the RF signal power level. The Dual-Tone calibration method proposed in [6] is robust and simple but the requirement of an additional RF signal generator is difficult in some applications. A new method was recently presented in [7]. But it is only used for applications requiring the relative phase between two successive transmission coefficient measurement (S_{21}) for PLL purpose. In the case of frequency channel sounder, it is necessary to determine the absolute phase of S_{21}. We present in this paper a five-port calibration method used for frequency channel sounder in the frequency band from 2.2 GHz to 2.6 GHz.. This method also offers the possibility to calculate the absolute delay of multi-paths in propagation channel. The method is validated by using data obtained from measurements. Five-port reflectometer design is presented in section II, In section III, the calibration method is developed. The measurement system is shown in section IV and the results are given in section V.

II- FIVE-PORT REFLECTOMETER

Five-port reflectometer implemented in micro strip technology and its layout are shown in Figure 1. It consists of a ring with five arms (two inputs and three outputs) and three RF (Radio Frequency) power detectors. The ring combines the RF signal and the Local Oscillator signal connected at two inputs. The resulting signals at the ring's outputs are detected by three RF power detectors. Each RF power detector consists of a RF Schottky diode(HSMS 2852) and a RC low pass filter. The base frequency voltages at the output of 3 detectors are measured and then the ratio between the two input incident waves, the RF signal and LO signal, is determined by post numerical processing. Five-port can be used as a VNA in order to measure the Scattering parameters, of a device under test. In our application, we only measure the S_{21}, the transfer function of the propagation channel.



(a)

(b)

Fig. 1. Five-port reflectomèter (a) and its layout(b)

III- CALIBRATION OF FIVE-PORT FOR FREQUENCY CHANNEL SOUNDER

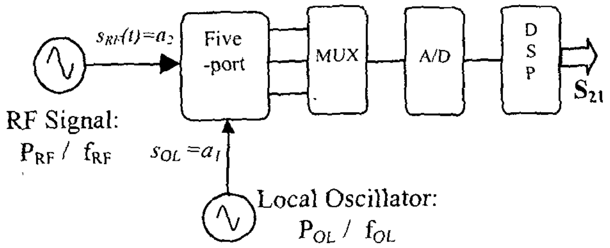


Fig. 2. System based on a five-port reflectometer to determine $S_{21} = a_2/a_1$

The system based on a five-port reflectometer to determine the transfer function S_{21} of the propagation channel is presented by the block diagram in Figure 2. It consists of a five-port, a multiplexed, an analog to digital converter and a digital signal processor. The complex transfer function S_{21} in the digital domain represents the complex ratio between the RF signal and LO signal. The RF and LO signals may be written as [7]:

$$v_{RF}(t) = \mathrm{Re}\{V_{RF}(t)\, e^{j(\omega t+\theta(t))}\} = V_{RF}(t)\cos(\omega t+\theta(t)) \quad (1)$$

$$v_{LO}(t) = V_{LO}\cos\omega t \quad (2)$$

$V_{RF}(t)$ and V_{LO} are the amplitudes of the RF and LO signals. ω and θ are RF pulsation and relative phase between RF and LO respectively.

The ring with five-arms performs an addition of the two input signals. So at the outputs 3, 4 and 5 of the ring, the signals have the form:

$$v_i(t)=\sqrt{a_i}\, V_{LO}\cos(\omega t+\gamma_i)+\sqrt{b_i}\, V_{RF}(t)\cos(\omega t+\theta(t)+\lambda_i)$$
$$i=3,4,5 \quad (3)$$

a_i, b_i are complex parameters which depend on the scattering parameters of five-port circuit

γ_i and λ_i are the phase of V_{LO} and the phase of $V_{RF}(t)$ at port i respectively.

The voltage values at the RF power detectors' outputs are:

$$v'_i = a_i V_{LO}^2 + b_i V_{Rf}^2(t) + c_i V_{RF}(t)\cos(\theta(t) - \Phi_i) \quad (4)$$

With $\Phi_i = \gamma_i - \lambda_i$ and $c_i = \sqrt{a_i}\sqrt{b_i}\, V_{LO}$.

$$v''_i = v'_i - a_i V_{LO}^2$$
$$= b_i V_{Rf}^2(t) + c_i\cos(\Phi_i)\, I(t) + c_i\sin(\Phi_i)\, Q(t) \quad (5)$$

where $I(t) = V_{RF}(t)\cos(\theta(t))$ and $Q(t) = V_{RF}(t)\sin(\theta(t))$ represent the real and imaginary parts of the complex envelop of RF signal.

The main idea of the calibration method suggested in [7] is to determine I and Q in equation (5) by observing the phase difference between Φ_i at power detectors' outputs. The calibration procedure consists of two main steps which allow us to determine:

+ In the first step, determination of the term $a_i V_{LO}^2$ by making $v_{RF}(t) = 0$ and measuring the voltages at detectors' outputs in equation (5)

+ In the second step: determination of I and Q in equation (5) by observation of the voltage values sampled at the three RF power detector outputs when $\theta(n) = n\,\Delta F$.

Where ΔF is the frequency difference between RF and LO signals

$n = 0..N$; $N = 2\Pi\, Fs/\Delta F$ and Fs is the sampling frequency.

However this calibration is applied to the cases where the absolute phase reference plane is not important as in receiver.

The frequency domain sounding technique requires a phase reference plane in order to determine the absolute delay of multi-paths in propagation channel. The reference plane is defined by taking the same reference plane for the input and output of the channel.

By repeating the three steps above for M = 401 frequencies from 2.2 GHz to 2.6 GHz , the transfer function of the channel in the digital domain $S_{21}(n)$ is determined as following [7]

$$H_{21}(n) = I(n) + jQ(n) = av'_3(n) + bv'_4(n) + cv'_5(n) + d \quad (6)$$

Where a, b, c, d are the complex constants of calibration which depend on Φ_i, a_i, b_i and V_{LO}.

The calibration constants are determined using measured voltage data. Their expressions are given in the paper [7].

IV- MEASUREMENT SYSTEM

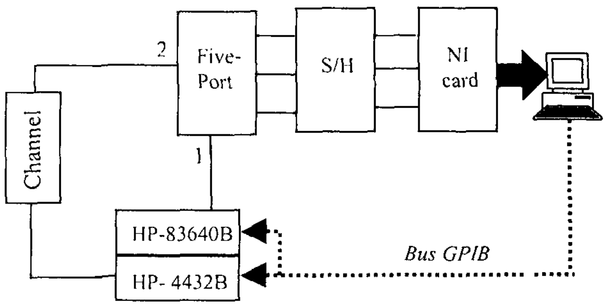


Fig. 3. Five-port arrangement for calibration

The measurement system is illustrated in Figure 3. The two RF generators HP 83643B and HP4432B are connected to RF five-port's input and LO five-port's input respectively. A Sample and hold (S/H) is used to freeze the signals at five-port's outputs for performing A/D conversion at the same time. A computer is equipped with one acquisition card (National Instruments PCI -16-E1) and one GPIB bus controller and a five-port reflectometer implemented in micro strip technology. The generators are controlled via the GPIB bus. The two generators are synchronized and delivered CW signal with a shift frequency $\Delta f = 100$ Hz. The acquisition card was set to acquire 100 points with sampling frequency of 10 KHz. (All the data acquired was processed by a software build in Borland C++). During calibration, the RF generator and LO generator are set at –15 DBm and 0 DBm respectively. The three voltages at three frequencies at five-port's outputs are shown in Figure 4. We can see clearly that when there is a frequency change, the three voltages change simultaneously.

V- RESULTS

The calibration procedure is performed using Matlab and the measurement data. The calibration constants calculated for 3 frequencies are summarized in table I. We can see that they are different at each frequency that's why the system should be calibrated at each frequency. Figure 5 shows the calculated values of S_{21} . The result in this figure confirms the accurate result of calibration because after reconstituting the I and Q from the three voltages v3, v4, v5, we obtain a circle in the complex plane which guarantees that the initial signal is well reconstituted.

In addition, in order to verify that it is capable of finding the absolute propagation delays by using this method, we used the cables which represent the ideal propagation channels. Each cable corresponds to one path. Before measuring, the system is calibrated by using the calibration method proposed. The transfer function of the channel is measured at each frequency and the impulse response of the channel is calculated by using Inverse Fast Fourier Transform (IFFT). In the first case, one cable of 4m was used. Figure 6 shows the results of channel impulse response. It can be seen that one path of 17.5 ns is well estimated. In the second one, the ideal channel which consists of two cables of 4 m and 8 m was tested. The result is shown in Figure 7. We can see from this figure that two paths are well found with the delay of 17.5 ns and 35 ns.. The comparison of values obtained with five-port system and with Vector Network Analyser are summarized in table II. The results measured with five-port system are very close to that obtained with VNA. The maximal error between two system is 1.7 %.

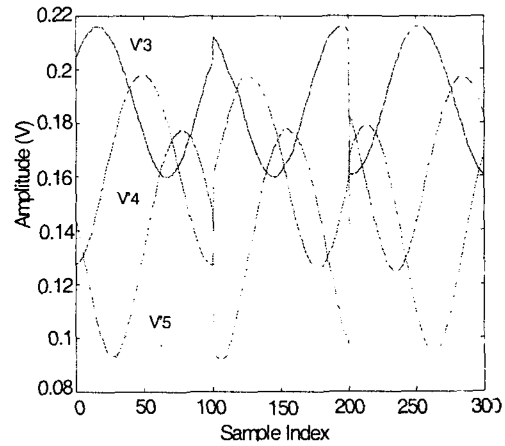


Fig. 4. Three voltages at five-port's outputs

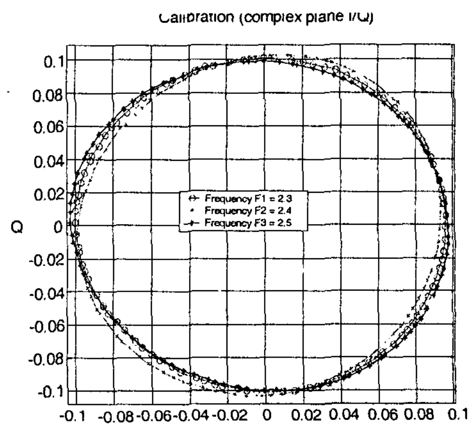
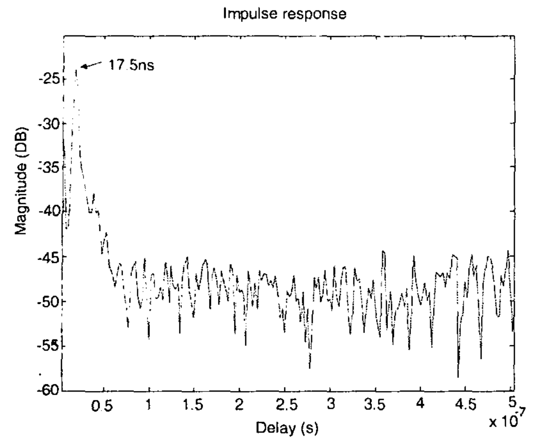


Fig.5. Constants of calibration (N=100, M=3)

Table I- Constants of calibration from measurement

Frequency	a		b		c		d	
	Magnitude	Phase (°)	Magnitude	Phase (°)	Magnitude	Phase (°)	Magnitude	Phase (°)
F1	7.9	30	8.54	163	15.42	-93	2	66
F2	8.96	60.8	8.88	-175.8	16.24	-75	3.14	93.6
F3	7.83	77.6	9	-101.9	20.79	-25.4	5.27	148



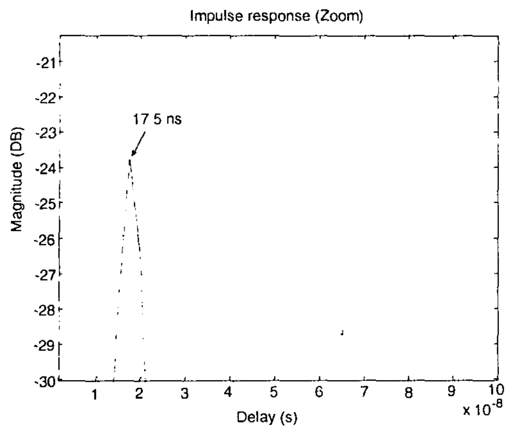


Fig. 6. Channel impulse response (one path)

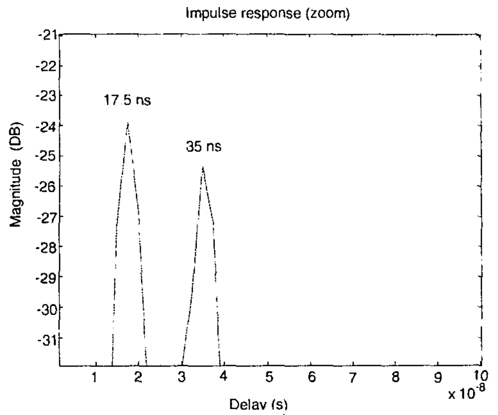
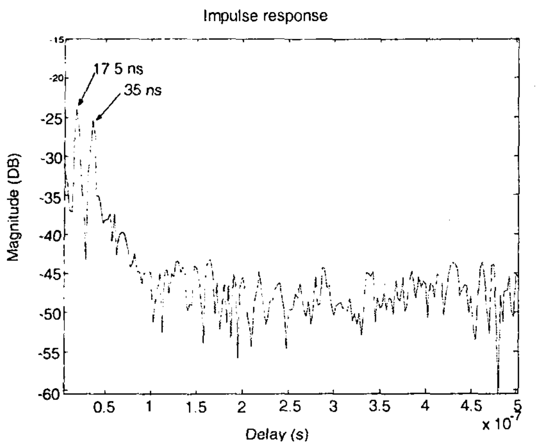


Fig. 7. Channel impulse response (two path)

Table II- Comparison of results

Case	Number of paths	Path number	Five-port system	VNA
1	1	1	17.5	17.75
2	2	1	17.5	17.75
		2	35	35.6



VI- CONCLUSION

The calibration method of five-port reflectometer applied to frequency channel sounder is presented. This method can determine the absolute delays of multi-paths in a propagation channel. The method is validated by using measurement data. For the future work, the channel will consist of eight antennas and eight five-port reflectometers at reception. The channel sounder based on frequency domain technique measures direction of arrival and time delay of multi-paths in the propagation channel.

REFRENCES

[1]- G. F. Engen, "The six-port reflectometer: an alternative network analyser," *IEEE Transactions on Microwave Theory and Techniques*, vol. 25, No. 12, pp 1075-1080, Dec 1977.

[2]- CG Miguelez, B. Huyart, E. Bergeault and L. Jallet, "A new automobile radar based on the six-port phase/frequency discriminator," *IEEE Transactions on Vehicular Technology*, Vol. 49, No. 4, July 2000, pp 1416-1423.

[3]- S.O. Tatu, E. Moldovan, Ke Wu, and R.G. Bosisio, "A new direct millimeter wave six-port receiver," *Microwave Symposium Digest, 2001 IEEE MTT-S International*, Vol. 3, pp. 1809 –1812, May 2001.

[4]- Frank Wiedmann, "Développements pour des applications grand public du réflectomètre six-portes: algorithme de calibrage robuste, réfletomètre à très large bande et réflectomètre intégré MMIC," *Thèse soutenue en juillet 1997 à l'ENST Paris.*

[5]- G. Neveux, "Démodulateur direct de signaux RF multi-mode et multi-bande en utilisant la technique « cinq-port »," *Thèse de l'ENST Paris, December 2003*

[6]- Ji Li, Renato G. Bosisio and Ke WU, "Dual-Tone Calibration of six-port junction and Its Application to the six-port Direct Digital Millimetric Receiver," *IEEE Trans on Microwave Theory and Techniques*, Vol.44, No. 1, January 1996.

[7]- F. R. De Sousa ; B. Huyart; R. N. de Lima. "*A new method for automatic calibration of 5-port reflectometers*," *IEEE MTT-S / SBMO International Microwave and Optoelectronics Conference, IMOC'2003. Actes de conférence* - Foz de Iguaçu - Brasil, 20-23 Sep 2003.

[8]- J.D Parsons, D.A Demery and A.M.D Turkmani, " Sounding techniques for wideband mobile radio channels: a review," *IEE Proceeding-I*, Vol. 138, no.5, October 1991.

[9]- A.Judson Braga, Van Yem VU, Bernard Huyart and Xavier Begaud, " Results on DoA finding system based on five-port discriminator," *IEEE IMS 2004 International Microwave Symposium.*