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Analysis of Phase and Time Jitter of Various Electronically Modulated Near Infra-Red Optical Waveforms for Deep Breast Tissue Imaging

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Abstract:

Breast Cancer is a second deadly cancer disease and more than 2 million new cases are being reported annually in recent years. Early diagnosis and mass screening is validated as an effective tool for better disease management. Development of non-invasive affordable first level screening techniques is required for efficient mass screening. The proposed system consists of a near infra-red optical transmitter connected with signal modulator and receiver coupled with a demodulator mechanism. A modulated optical waveform provides deep tissue details by high tissue penetration. The constant signal wave form generator and signal oscilloscope were connected for wave generation and measurement. The optical waveform is digitally modulated by eight modulation techniques at the transmitter side and demodulated at the receiver side. The normal spot and cancerous spot of the breast phantom model are placed in the path of optical transmitter and the reflected signal is received by the receiver prior to demodulation. Phase Jitter, Time Jitter and 3dB noise level were measured from the received signal for the normal as well as cancerous spot of the breast phantom. The difference of phase and time jitter between normal and cancerous spot is observed. There is no significant variation is observed in the 3dB noise level. Phase and time jitter variation among different modulation techniques is provided. The results are indicative that the proposed method can be used for breast imaging as a first in-line imaging tool for mass screening. Also the proposed system can be utilized along with ultrasonography as a hybrid imaging modality.

Keywords: *Breast Imaging, Phase Jitter, time jitter*

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Introduction

Breast Cancer is a global health menace with more than 2 million new cases are being diagnosed globally every year [1,2]. Breast Cancer predominately affects women [3] by endangering their health and lives [4]. Early diagnosis and better understanding of the cancer morphology is a key tool in the management and treatment of the Breast Cancer [5,6]. Mass screening is a strategy for early diagnosis of breast tumor in vulnerable group [7,8]. Mammography is a Golden standard in the diagnosis of Breast Cancer adjutant to Clinical biopsy [9-10]. Next to Mammography Ultrasonic is being used widely for diagnosis of breast masses [11]. These two imaging modalities have practical implications in mass public screening programs [12]. Optical and Near Infra-red (NIR) imaging techniques are being investigated in many studies as a tool for initial level breast cancer screening.[13,14,15]. Optical and NIR based breast imaging modalities are non-ionizing, non-invasive and have faster image acquisition capabilities [16-18].

Optical imaging provides functional details about cancer vascularity and also provides details about blood oxygen saturation level [19]. Optical tomography is validated to be an effective technique in cancer margin assessment during surgery [20, 21]. Optical imaging techniques have the capability to detect as well as measure the blood in tissue noninvasively without any contrast agents or ionizing radiation [22]. Oxygenation and physiological details of breast blood volume were obtained with non-invasive optical imaging system. Also tumor vessels can also been detected using optical imaging. Details of hemodynamic effects can be measured using NIR optical imaging system [23]. The tissue composition of the breast tumors is characterized using the optical spectral imaging method [24].

Smaller lesions of less than 5mm size shall be quantitatively imaged using NIR optical imaging with finite element solution of photon diffusion on breast tissue. The propagation characteristics of the optical wave provide details used to differentiate between normal and cancerous tissue [25]. The imaging of tumor angiogenesis is critical in the advanced cancer patients. Optical imaging overcomes the effect of high level of distortion and heterogeneous nature of advancer breast. The heterogeneous vascular distribution is effectively imaged by optical imaging which improves disease prognosis monitoring ad treatment [27].

Background of the Study

Various studies have been reported in the NIR optical imaging for biomedical applications. Unlike Other breast imaging modalities such as Ultrasonography or

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mammography, the optical breast imaging techniques is not able to image the deep and complex breast tissues. This is due to scattering of the optical waves by the tissues. Although Near Infrared based optical imaging is able to penetrate the tissue up to several millimeters it is also not able to achieve deep tissue imaging. In a detailed review [35], use of multiple scattered waves is evidenced to be containing deep tissue information. Also the study highlights the use of convergence lens to focus multiple scatter waves for better imaging results of deep tissues. A reflection matrix based schema is proposed for overcoming the inverse scattering issues.

Imaging of deep tissues with polarized parametric imaging was studied in a study [36]. A polarized optical waveform was studied for its efficiency in identifying deep tumor spots in phantom models. In yet another study [37], the deep tissue penetration of biological tissues was attempted by waveform shaping of time inversed ultrasonically encrypted light.

Second and third window of the Near Infrared Optical spectra was studied for its effectiveness in deep tissue penetration and imaging [38]. The study concluded that these windows offer a higher penetration with less scattering making them a viable option for deep tissue imaging.

In a recent study, deep neural network based encoder-decoder architecture was proposed for deep tissue optical imaging [39]. The experimentation was conducted by training the neural network with a larger dataset of optical imaging of biological tissues that are influenced by Gaussian noise and scattering

Intensity modulated optical waves were transmitted to deep tissue samples and change in phase of the waves are observed up to a depth of approximately 11mm. These modulated waveforms in frequency domains were found to be effect for deep tissue imaging [40].

Optically diffused imaging techniques for deep tissue imaging along with several advance methods such as deep learning and enhancements in optical data acquisition were reviewed in a study. Near infrared pulses of smaller durations were used in time-domain based optical imaging process. Where as in frequency domain based optical imaging modulated wave forms shall be used. 2 to 5mm imaging of tissues in depth is obtained with the spatial domain based diffused imaging modality. At different phases of the optical waveform with respect to spatial coordinates imaging data were captured [41].

Mapping of zinc ion based on selective photo acoustics detection was experimented [42]. Unlike optical coherence imaging, optical diffusion and photo acoustics methods are able to penetrate deep tissues up to 5cm [43].

Recent studies show that, deep tissue mapping in optical imaging is a key challenge which affects the overall usability of the optical imaging technique in medical imaging. However Near infrared optical imaging possess number advantages. The current study validates the applicability of phase jitter and time jitter of optical waveforms as tool for deep tissue and breast tissue imaging.

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Materials and Methods

Design and Experimental Setup of the System

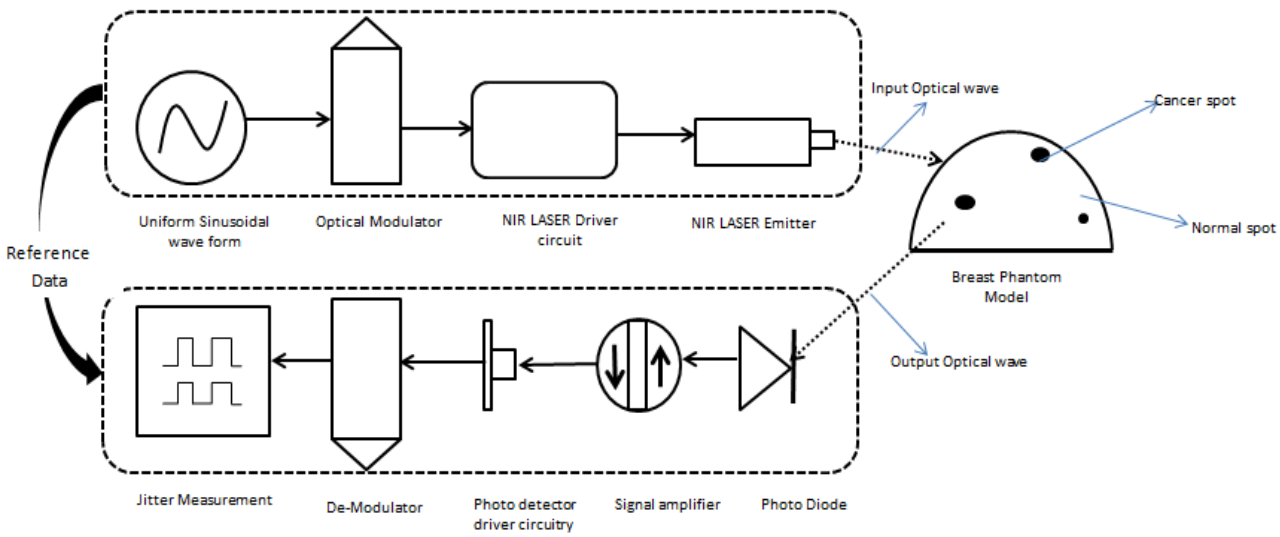

Figure 1: Experimental Test Bench

The test bench setup for measurement of phase jitter, time jitter and 3dB noise level of optical waveform over a breast phantom model is shown in figure 1. The test bench primarily consists of four sections namely the optical modulator and emitter section, the optical wave section which undergo changes in the path of its travel, the breast phantom model section and the receptor along with the demodulator and measurement circuitry.

The optical modulator section consists of mono coherent Near Infrared LASER diode of wavelength 750nm and output power less than 1 mw. The diode is connected to a driver circuit which will combine the modulated signal from modulator to the electrical power required for driving the LASER diode. The signal modulator will capable of modulating the uniform sine wave signal of frequency 3935Hz, received from the signal generator with eight types of modulation techniques. The eight modulation techniques used in this study are Pulse-code modulation (PCM) ,Phase-shift keying (PSK) ,Adaptive delta modulation (ADM) ,Quadrature Phase Shift Keying (QPSK) ,Amplitude-shift keying (ASK) ,Pulse amplitude modulation (PAM) ,Pulse width modulation(PWM) and Pulse position modulation (PPM). These modulation techniques provide robustness to the signal against any noise.

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The modulated waveform converted in to its equivalent optical beam through the LASER diode. The mono coherent optical signal is made to fall over the breast cancer phantom model. The part of the optical waveform falling on the phantom model undergoes refraction, reflection, diffraction and scattering.

A receptor unit is placed in the path of the reflection of the waveform. The receptor module consists of a photodiode driven by a signal conditioner and signal amplifier circuitry that will enhance the weak signal. The amplified signal is demodulated with the demodulation technique corresponding to the modulation technique used in the emitter part. The demodulated signal is fed to the jitter measurement system. Phase jitter, time jitter and 3dB noise level are the three parameters measured in the measurement block.

The breast phantom model used in this study is standard phantom model mad of silicone material which mimics the human breast tissue property and anatomy. The phantom model consists of breast tumor spots, micro calcification and normal tissue spots. These phantom models are widely used for imaging studies, elastography studies and standardization of imaging equipment's [28-33].

Experimental Condition

The experimental room condition such as temperature, humidity and pressure is maintained consistently throughout the experimentation and measurement process. The experimentation is conducted at night to avoid solar irradiation and in dark condition without any external light presence. A beacon signal is transmitted to the receptor directly without the test phantom model for measuring external noise and instrumentation error noise.

Initially the Pulse Position Modulation is used for modulating the waveform and its corresponding phase jitter, time jitter and 3dB noise levels were recorded. The measurement is repeated for all other modulation techniques namely PCM, PSK, ADM, QPSK, ASK, PAM and PWM.

The propagation of the NIR optical wave in a human breast is characterized by the following equation [34]

$$\frac{\partial U(\vec{r},t)}{\partial t} + c\mu_a U(\vec{r},t) - c\nabla.\left[D\nabla U(\vec{r},t)\right] = q(\vec{r},t)$$

Where U is the density of photon, q is the strength of origin, c is the velocity of light in the medium, and D = 1/3_μa + μs_ is the diffusion coefficient of the medium. μa , μs are the

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coefficient of absorption and scattering respectively, which are the two important parameters of consideration in the image reconstruction process.

Phase Jitter

Fluctuations in the phase of the signal represented in frequency domain

Time Jitter

It is the time domain representation of the fluctuation of a signal

Intensity of noise is measured in dB scale and represented as N in dB

Results and Discussion

The phase jitter of pulse position modulation under normal tissue is 7.7359 and the corresponding time jitter is 859.55pico seconds. The same data signal is set to pass through cancer tissue. The phase jitter and time jitter measured for cancer tissue were 9.8414 and 1.0934nano seconds respectively.

The phase jitter of pulse width position modulation for normal tissue is 9.8754 and the corresponding time jitter is 1.0972nano seconds. The same data signal is set to pass through a cancerous tissue. The phase jitter and time jitter measured under cancer tissue were 10.196 and 1.1329nano seconds respectively.

The phase jitter of pulse amplitude modulation for normal tissue is 9.8598 and the corresponding time jitter is 1.0955nano seconds. The same data signal is set to pass through a cancerous tissue. The phase jitter and time jitter measured for cancerous tissue were 10.445 and 1.1605nano seconds respectively.

The phase jitter of amplitude shift keying modulation for normal tissue is 9.5719 and the corresponding time jitter is 1.0635nano seconds. The same data signal is set to pass through a cancerous tissue. The phase jitter and time jitter measured under cancer tissue were 9.6704 and 1.0744seconds respectively. The phase jitter of quadrature phase shift keying modulation for normal tissue is 9.9088 and the corresponding time jitter is 1.1009nano seconds. The same data signal is set to pass through a cancerous tissue. The phase jitter and time jitter measured under cancer tissue were 10.539and 1.1710nano seconds respectively.

The phase jitter of adaptive delta modulation under normal tissue is 9.7710 and the corresponding time jitter is 1.0856nano seconds. The same data signal is set to pass through a cancerous tissue. The phase jitter and time jitter measured under cancer tissue were 11.200 and 1.2444nano seconds respectively.

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The phase jitter of phase shift keying modulation for normal tissue is 9.7122 and the corresponding time jitter is 1.0791nano seconds. The same data signal is set to pass through a cancerous tissue. The phase jitter and time jitter measured under cancer tissue were 9.9111 and 1.1012seconds respectively.

The phase jitter of pulse code modulation for normal tissue is 9.3729 and the corresponding time jitter is 1.0414nano seconds. The same data signal is set to pass through a cancerous tissue. The phase jitter and time jitter measured under cancer tissue were 9.9000 and 1.1000 nano seconds respectively.

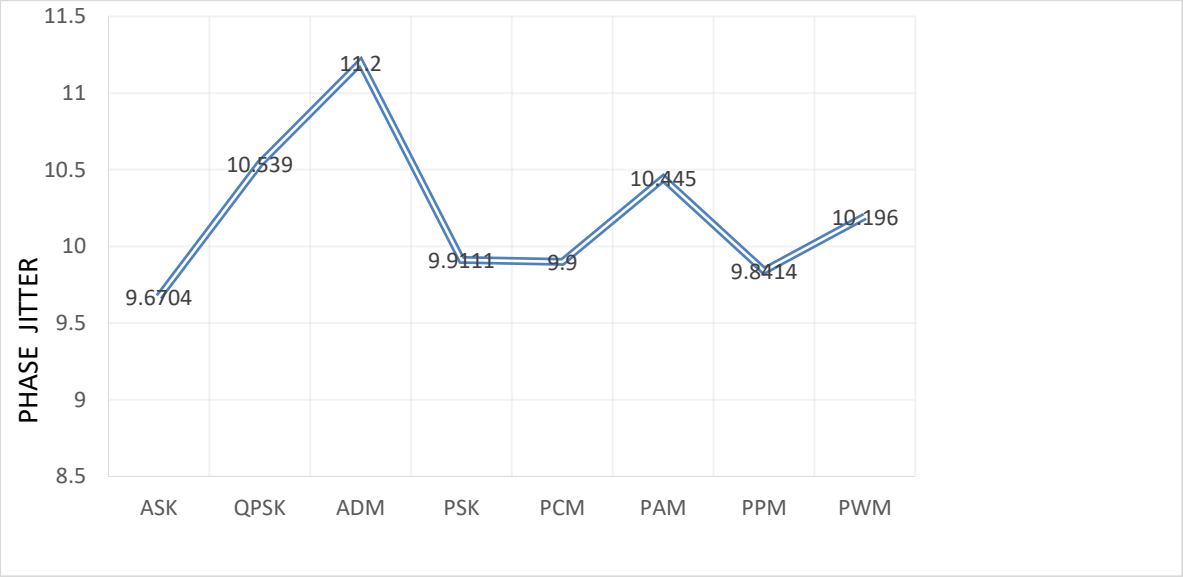

Figure 2: Phase jitter vs Modulation schemes

While transmitting a laser beam containing data over cancer tissue PPM and ASK modulation schemes found to be least affected by the cause of cancer. The PPM and ASK modulation schemes have a phase jitter of 9.8414rad and 9.6704rad, which were comparatively low jitter than other modulation schemes employed. Also the time jitters of PPM and ASK also low than other modulation techniques. In this analysis adaptive delta modulation is underneath performer over cancer which owns a phase jitter value of 11.200rad and a time jitter of 1.2444nsec. The phase jitter of other PWM,PAM, PSK, QPSK and PCM were around 10.5rad.

Table 1: Phase Jitter And Time Jitter Of OCM Signal With Various Modulation Schemes Under Normal And Cancer Tissue

Modulation	Tissue	Phase Jitter	Time Jitter	N In Db
ASK	Normal Tissue	9.5719	1.0635 nsec	6
	Cancer Tissue	9.6704	1.0744 sec	114
QPSK	Normal Tissue	9.9088	1.1009 nsec	24
	Cancer Tissue	10.539	1.1710 nsec	24
ADM	Normal Tissue	9.7710	1.0856 nsec	24
	Cancer Tissue	11.200	1.24444 nsec	12

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PSK	Normal Tissue	9.7122	1.0791 nsec	24
	Cancer Tissue	9.9111	1.1012 sec	12
PCM	Normal Tissue	9.3729	1.0414 nsec	12
	Cancer Tissue	9.9000	1.1000 sec	12
PAM	Normal Tissue	9.8590	1.09555 nsec	30
	Cancer Tissue	10.445	1,1605 nsec	30
PPM	Normal Tissue	7.7359	859.55picosec	12
	Cancer Tissue	9.8414	1.0934nsec	30
PWM	Normal Tissue	9.8754	1.0972nsec	30
	Cancer Tissue	10.196	1,1329nsec	12

Conclusion

We developed a NIR Optical Waveform based imaging modality which uses the Phase Jitter and Time jitter of the optical waveform. A uniform waveform modulated by several modulation techniques were experimented one by one. Phase Jitter and Time jitter difference between normal breast phantom spot and cancerous breast phantom spot were recorded. It is evident from the analysis that while transmitting a modulated optical signal over a normal and cancer tissue, the performance of signal suffers to a quantifiable amount It is apparent from the experimental results that over cancer tissue, the signal strength immunity level of PPM and ASK modulation techniques high than other modulation techniques employed. Very high phase jitter was observed in Adaptive Delta Modulation technique making it as candidate of interest in modulation of optical waves for breast imaging. Experimental results shown that ASK and PPM modulation techniques provide high robustness to the optical signal hence only low jitter variation is observed between normal and cancerous tissue.

The difference of jitters among the normal and cancerous spots indicates that the technique can be validated further for usage as an initial screening tool for breast screening mass public programs.

Ethical Statement

The authors declare that no human experimentation or animal experimentation was involved. All the institutional ethical guidelines were adhered with.

Conflict of Interest:

The authors declare that there is no conflict of interest

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SUPPLEMENTARY DATA

Annexure: Results Window of Phase Jitter, Time Jitter and 3dB noise measurement of various NIR optical waveforms modulate by different modulation techniques over a breast phantom model under normal and cancerous spot.

1. PWM Modulation Under Normal and Cancer Tissue Sample

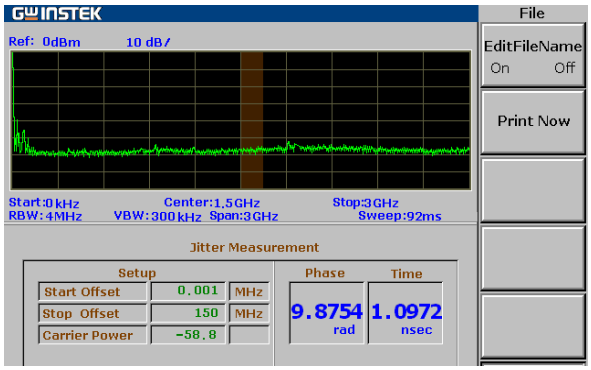

Fig. 3.1 Phase Jitter of OCM signal with PWM under normal tissue

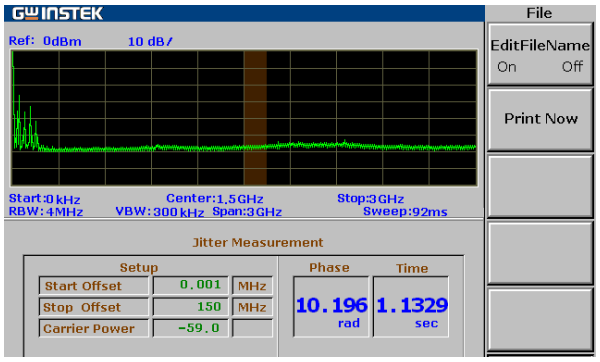

Fig. 3.2 Phase Jitter of OCM signal with PWM under cancerous tissue

2. PAM Modulation Under Normal and Cancer Tissue Sample

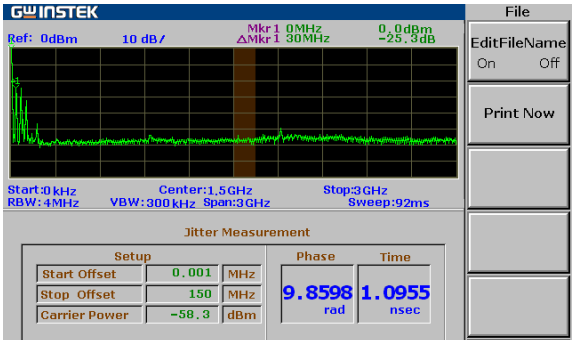

Fig. 3.3. Phase Jitter of OCM signal with PAM under normal tissue

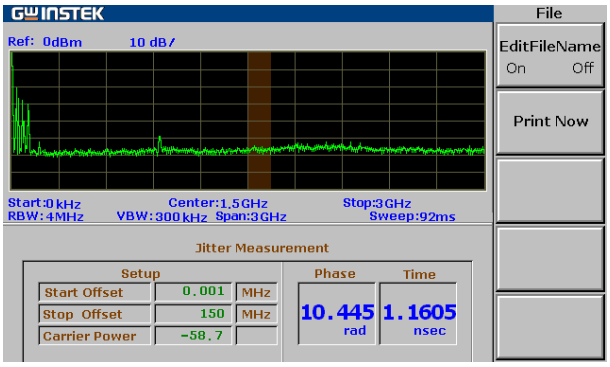

Fig.3.4 Phase Jitter of OCM signal with PAM under cancerous tissue

3. ASK Modulation under Normal and Cancer Tissue Sample

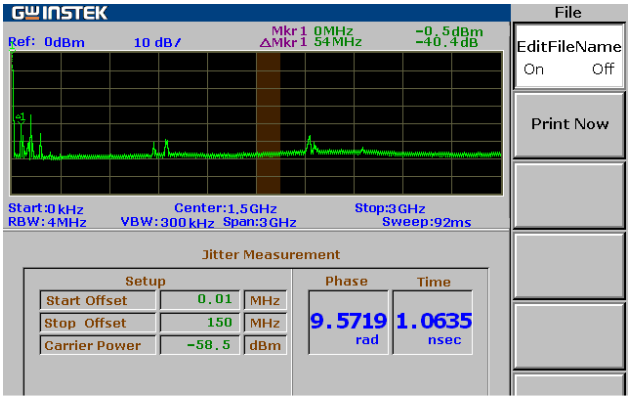

Fig. 3.5 Phase Jitter of OCM signal with ASK modulation under normal tissue

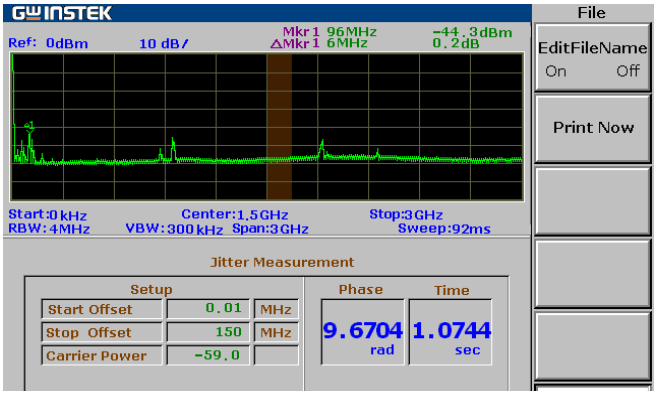

Fig.3.6 Phase Jitter of OCM signal with ASK modulation under cancerous tissue

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4. QPSK Modulation under Normal and Cancer Tissue Sample

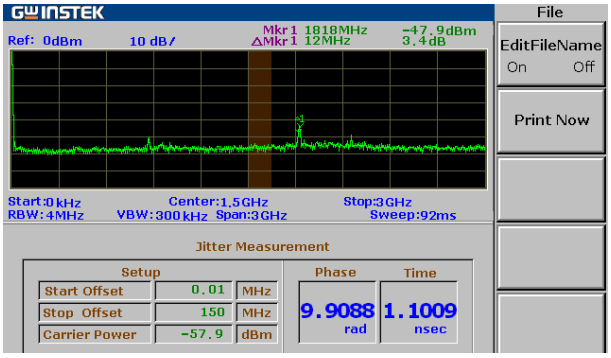

Fig. 3.7. Phase Jitter of OCM signal with QPSK modulation under normal tissue

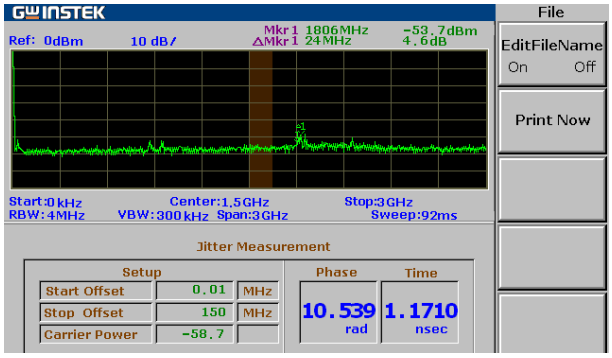

Fig. 3.8 Phase Jitter of OCM signal with QPSK modulation under cancerous tissue

5. ADM Modulation under Normal and Cancer Tissue Sample

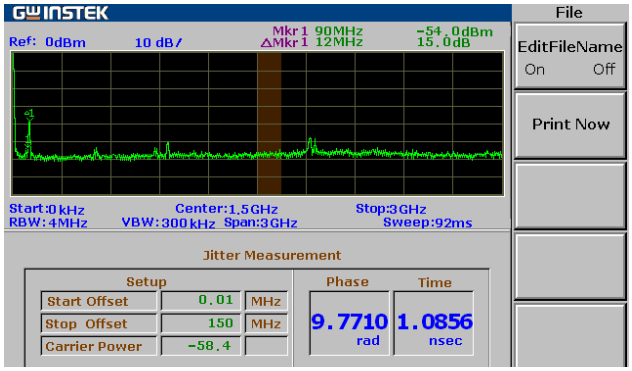

Fig.3.9. Phase Jitter of OCM signal with ADM under normal tissue

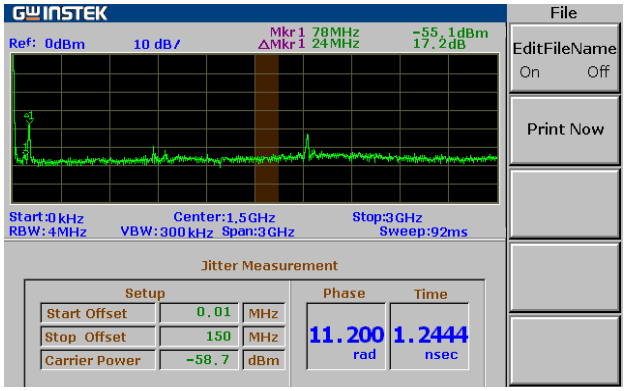

Fig.3.10. Phase Jitter of OCM signal with ADM modulation under cancerous tissue

6. PSK Modulation under Normal and Cancer Tissue Sample

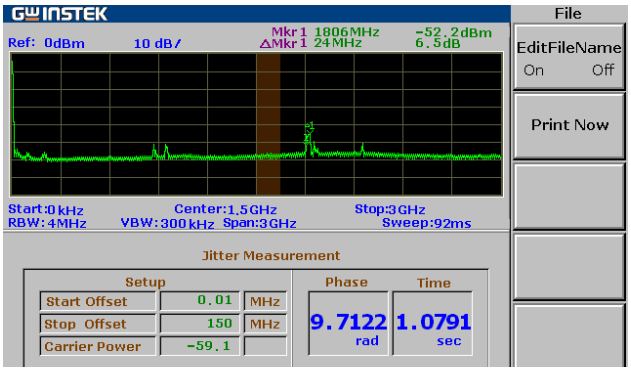

Fig. 3.11. Phase Jitter of OCM signal with PSK under under normal tissue

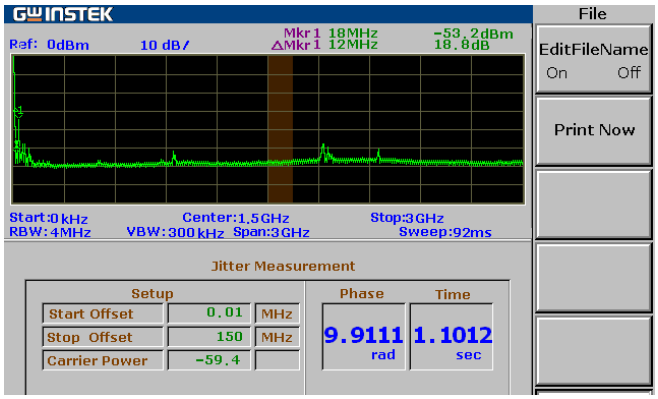

Fig.3.12. Phase Jitter of OCM signal with PSK modulation under cancerous tissue

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7. PCM Modulation under Normal and Cancer Tissue Sample

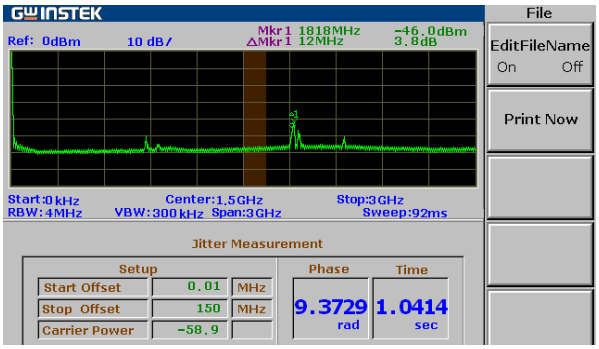

Fig.3.12. Phase Jitter of OCM signal with PCM under under normal tissue

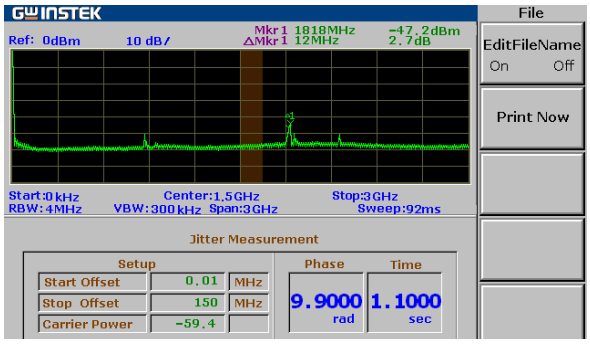

Fig.3.13. Phase Jitter of OCM signal with PCM modulation under cancerous tissue

8. PPM Modulation under Normal and Cancer Tissue Sample

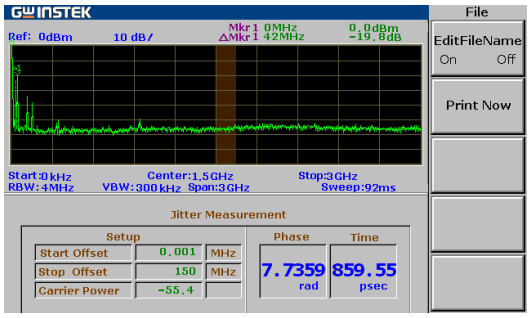

Fig.3.14. Phase Jitter of OCM signal with PPM under normal tissue

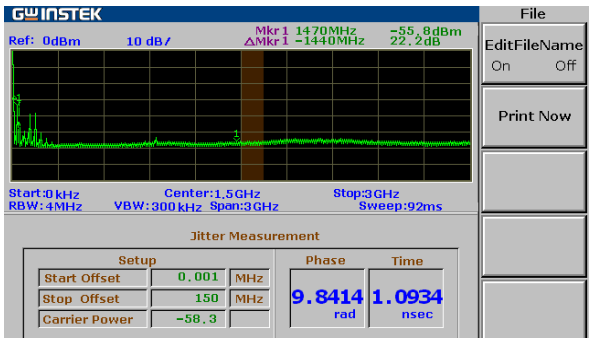

Fig.3.15. Phase Jitter of OCM signal with PPM under cancerous tissue

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