NPT Measuring Instrument Based on Microwave Phase and Amplitude Detecting Technology

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Abstract. The traditional NPT (Nocturnal Penile Tumescence) measures mainly base on pressure or resistances measuring which can’t express penis parameters such as the Length, hardness and blood supply in night perfectly. The measuring instrument in this paper is based on the microwave phase and amplitude detecting technology chip—AD8302. Place the transmitting antenna and receiving antennas with different positions in penis. Through the differences of Phase and amplitude that the transmitting signal reaches the different receiving antennas, we can judge the spongy body’s length and blood supply variations, in the same time we also can get the hardness information based on the pressure sensor. So this instrument can achieve the Precision without invasive outside body multi–parameter detecting.

Introduction

Erectile Dysfunction (ED) refers to that penis cannot be able to attain and maintain hard enough for at least 6 months to get satisfied in sexual life. ED is a common disease among not only the elder males but also the younger ones. ED has become a medical and social concern that jeopardizes male physical and psychological health and has severe negative impact on family harmony, which deserves to be taken seriously\textsuperscript{[1]}.

International Index of Erectile Function (IIEF-5) can give a preliminary assessment of these verities of ED\textsuperscript{[2]}. According to major pathogenesis, ED can be classified into psychological cause and organic cause. Psychological ED: it always starts suddenly under certain circumstances or occasions. But it can be normal under other circumstances or occasions (masturbation etc.). Spiritual psychology such as marriage relationship, personal emotion and social causes etc. can be the inducing factors of ED. Such ED patients still have nocturnal penile tumescence. Organic ED: it starts unconsciously and gets worse gradually, or it is affected by operations, traumatism or drugs. Under any circumstances or occasions penis cannot erect normally or maintain erected long time enough. No nocturnal penile tumescence or penile erection decreases obviously in such case.
NPT is a spontaneous erection of the penis during sleep. In general, all men have NPT since their infancy to their old age, usually 4-6 times and lasting 120-150 minutes during a night. The duration of NPT decreases with age. Men above 60 years old still have penile erections for about 60 minutes per night. NPT is a part of autonomic nerve system activities, and should be seen as an objective manifestation of penile activity in human sub-consciousness. NPT also is a biological indicator reflecting the capability of penile erection while being awaken[^3]. The existence of NPT therefore is considered as a reliable method to ascertain whether a given case of erectile dysfunction (ED) is psychological or organic in origin[^4].

Nowadays two ways are clinically widely used to test NPT:

First is the Rigiscan system. The device is designed on the principle that the variation of the physical quantity (tension) is converted by the electrode plate into the fluctuation of electric quantity. Testing method: two testing rings are placed on the front-end and root of penis before sleep. The holter that was bound on hip makes synchronous records of the thickness and hardness of penis. The records then are analyzed via certain software. This test is simple, easy and non-invasive. Normal parameter: 3-6 times erecting per night, 10-15 minutes each time, hardness > 70%[^5]. Although the hardness and duration of penile erection can be viewed directly on measuring charts, Rigiscan cannot make precise judgment of ED original cause, nor reflect the variation of blood flow before and after penile erection.

Second is NEVA (nocturnal electro-bio-impedance volumetric assessment) system[^6]. In this device, three electrodes connect to the base and tip of the penis as well as the hip, which represent the ground electrode. The electrodes monitor changes in the relative volume of the penis by measuring the resistance to electric current flow or the impedance, which changes with increasing penile cross-sectional area and length during a nocturnal erection. These impedance changes are converted to data. The device records the times, duration, and particularly blood volume increase of NPT events[^7]. The standard of diagnosis is as following:

<table>
<thead>
<tr>
<th>Volume change of penile blood over baseline (%)</th>
<th>t/min</th>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;130</td>
<td>&gt;15</td>
<td>Severe reduction of blood flow</td>
</tr>
<tr>
<td>130-171</td>
<td>&gt;15</td>
<td>Moderate reduction of blood flow</td>
</tr>
<tr>
<td>171-200</td>
<td>&gt;15</td>
<td>Light reduction of blood flow</td>
</tr>
<tr>
<td>&gt;201</td>
<td>&gt;5</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Rigiscan is partial to be used in testing variation of hardness of penile erection. Rigiscan is traditionally used to differentiate between psychogenic and organic ED[^8], but it has one-sideness in assessment of penile erection. Some scholars have pointed out the limitations of Rigiscan in NPT testing[^9].

NEVA is partial to be used in testing the variation of blood volume in penis. NEVA is based on the technology of electro-bio-impedance. The three measuring factors are cross-sectional area, length and internal medium. Variation of the three measuring factors can be detected during penile erection. But NEVA is less accurate in quantifying, especially when the subjects suffer hyperlipidemia, diabetes and vascular diseases. Blood flow dynamic in penis changes obviously resulting in larger variation in electro-bio-impedance, which leads to even more errors in testing result. In addition, NEVA is designed according to males in European and American countries only, lacking of worldwide data support.
In the view of above, we hereby have developed a device that is based on microwave phase and amplitude technology to measure the length, thickness, hardness, duration and variation of blood volume of NPT. The development of the device has a significant clinical and scientific value in describing NPT and identifying ED cause in origin.

The Principle of Radio-frequency Probe

General Design

Phase and amplitude detection chip can convert the phase and amplitude differential of two channel of identical frequency signals into corresponding voltage differential. It is bound to have a differential between the phase and amplitude of the two signals that get from two identical frequency signals through different pathways. We hereby take use of the differential to measure parameters such as length and attenuation. A typical case is the phase and amplitude detection chip AD8302 produced by ADI[10].

In that way, we setup a radiating point and two measuring points around penis: the signal radiating point is setup on the root of penis, while the two measuring points right underneath the signal radiating point and near front-end coronary groove. The relative position of two measuring points changes with change of penis, thus reflecting the change of penis in length; the variation of amplitude between the two measuring points and the radiating point reflects the change of blood volume in penis.

System Design Scheme

The system consists of the following parts:

**Signal trans-receiver.** Micro-strip antenna is used as signal trans-receiver, (See fig.1) which is consisted of radiating layer, medium layer and reflecting layer. Antenna working at frequency of 2.5-2.7GHz can reach technological indicators of gains > 5dBi and VSWR<2.

![Figure 1. Micro-strip patch antenna structure.](image1)

![Figure 2. Micro-strip antenna structure.](image2)
Hereby we setup the frequency of 2.6GHz, w=20.1mm, L=19.6mm, h=4mm, and the patch with 0.018mm in thickness. (See fig 3: Antenna Radiation Pattern and Gain) The maximum gain is about 5dBi. As shown in fig 4 the optimum point of standing wave is 1.2382:1.

![Figure 3. Antenna simulation radiation pattern.](image)

![Figure 4. Antenna simulation standing wave.](image)

**Signal generator.** 10MHz high-precision constant signals are generated by constant temperature crystal oscillators, then frequency-multiplied by phase-locked loops to 2.5GHz-2.7GHz, and transmitted by antenna after amplified by power-amplifier.

**Signal phase comparator.** Signal phase comparator receives signals, and then converts signals of differential of phase-voltage, and amplitude -voltage by phase and amplitude comparator chip AD8302. Microcontroller collects these signals that then are stored in data memory modules.

AD8302 has three main modes: measuring, controller, and level-comparator. We take use of the measuring mode in the paper (See Fig 5).
According to the data in AD8302 chip, when $V_{MAG}$ and $V_{PHS}$ directly connect with chip feedback setting input pin MSET and PSET, chip measuring mode will work on the default slope and central point that change with partial pressure of MSET and PSET. In the paper, measuring circuit works on the default slope and central point, the phase measuring equation in low frequency is as following $^{[11][12]}$:

$$V_{PHS} = -R_F I_\Phi(l \Phi(V_{INA}) - \Phi(V_{INB})| -90^\circ) + V_{CP}$$  \hspace{1cm} (1)

The slope $R_F I_\Phi$ is 10mV/\(\circ\), central point $V_{CP}$ 900mV, phase differential gap 90°, phase scope 0°~180°, output voltage range 1.8V~0V. The ideal phase response curve under the default measuring mode is as following (See Fig.6):

Figure 6. The ideal phase response curve under the default measuring mode.

Time interval is 1 second for data collection, that is, every other 1 second all collected data are transmitted and saved into upper computers via wireless transmitters.

Meanwhile, pressure sensor integrated in the system is used to test the variation of penis hardness.

**Measuring Principle**

As shown in Fig 7, L1 and L2 respectively stand for the distance from antenna phase center to antenna 1 and 2 in the condition of penile erected.
According to conversion relation of wave length $\lambda$ and phase, the phase differential conforms to the following equation:

$$
\Delta\phi = \phi(V_{INA}) - \phi(V_{INB}) = \frac{L_2 - L_1}{\lambda}
$$

Combining the Equation (1), the voltage phase differential is as following:

$$
V_{PHS} = -R_1 I_\phi (|\Delta\phi| - 90^\circ) + V_{CP}
$$

$L1'$ and $L2'$ respectively stand for the distance from antenna phase center to antenna 1 and 2 in the condition of penile weakened. According to conversion relation of wave length $\lambda$ and phase, the phase differential conforms to the following equation:

$$
\Delta\phi^* = \phi(V'_{INA}) - \phi(V'_{INB}) = \frac{L_2 - L_1}{\lambda}
$$

Combining the Equation (1), the voltage phase differential is as following:

$$
V_{PHS}^* = -R_1 I_\phi (|\Delta\phi^*| - 90^\circ) + V_{CP}
$$

The gap of the above two voltage value is as following:
\[ \Delta V = V_{PHS} - V_{PHS} \]
\[ = -R_f I \phi (\Delta \phi - 90') + V_{CP} + R_f I \phi (|\Delta \phi| - 90') - V_{CP} \]
\[ = -R_f I \phi (\Delta \phi - |\Delta \phi|) \]
\[ = -R_f I \phi \left( \frac{L_2 - L_1}{\lambda} - \frac{L_2 - L_1}{\lambda} \right) \]
\[ = -R_f I \phi \left( \frac{L_2 - L_1 - L_2 + L_1}{\lambda} \right) \]
\[ = -R_f I \phi \left( \frac{\Delta L_2 - \Delta L_1}{\lambda} \right) \]

The voltage gap \( \Delta V \) is in direct proportion to the difference between the varied values of these two lengths. Change of \( L_1 \) from weakened to erected (mm level) is a small amount compared to that of \( L_2 \) (cm level). Hence the above calculation can be simplified as following:

\[ \Delta V = -R_f I \phi \left( \frac{\Delta L_2}{\lambda} \right) \]  
(7)

According to the angle \( \Theta \) between the radiating antenna to the receiving antenna 2, the actual change in penile length \( \Delta L \) is as following:

\[ \Delta L = \frac{-\Delta V \cdot \lambda \cdot \cos \theta}{R_f I \phi} \]  
(8)

Blood Volume Calculating Basis Shown in figure, under the condition of penile erection, \( \varepsilon \) stands for the dielectric constant between the phase center of radiating antenna to receiving antenna 1 and 2, \( \varepsilon (B) \) is hereby the function that reflects the situation of blood volume in penis.

Given the signal of radiating antenna is set as \( P \Sigma \), input power as \( P_i \), antenna gain factor as \( G_i \), the field intensity in maximum radiation direction to the point \( \text{“r”} \) of actual antenna in free space is as following:

\[ |E_0| = \frac{\sqrt{60PG_i}}{r} \]  
(9)

Based on the relation of electric field and Poynting vector (power):

\[ S_0 = \frac{|E_0|^2}{2400\pi} \]  
(10)

Given the gain factor of receiving antenna is set as \( G_R \), Effective receiving section as \( A_e \), the power received by receiving antenna away from point \( \text{“r”} \) of radiating antenna is as following:
\[ P_R = S_0 \cdot A_r = \frac{P_i \cdot G_i \cdot \lambda^2 G_R}{4\pi r^2} \quad \text{(11)} \]

L1 and L2 respectively stand for the distance between the two receiving antennas to the radiating antenna. The power received by the two receiving antennas as following:

\[ P_{R1} = S_0 \cdot A_r = \frac{P_i \cdot G_i \cdot \lambda^2 G_R}{4\pi L_1^2} \quad \text{(12)} \]

\[ P_{R2} = S_0 \cdot A_r = \frac{P_i \cdot G_i \cdot \lambda^2 G_R}{4\pi L_2^2} \quad \text{(13)} \]

The ratio of the radiating power and receiving power as above is defined as the basic transmission loss in free space, that is:

\[ L_{bf1} = \frac{P_i}{P_R} = \left(\frac{4\pi L_1}{\lambda}\right)^2 \cdot \frac{1}{G_i G_R} \quad \text{(14)} \]

\[ L_{bf2} = \frac{P_i}{P_R} = \left(\frac{4\pi L_2}{\lambda}\right)^2 \cdot \frac{1}{G_i G_R} \quad \text{(15)} \]

Measured in decibels unit as following:

\[ L_{bf1} = 10\log \frac{P_i}{P_{R1}} = 32.45 + 20\log f (MHz) + 20\log L_1 (km) - G_i (dB) - G_R (dB) \quad \text{(16)} \]

\[ L_{bf2} = 10\log \frac{P_i}{P_{R2}} = 32.45 + 20\log f (MHz) + 20\log L_2 (km) - G_i (dB) - G_R (dB) \quad \text{(17)} \]

Compared to the free space, in the real condition of penile blood supply there is an additional factor A as channel attenuation factor, which changes according to dielectric constant \( \varepsilon \) (B). The channel attenuation caused by blood supply can be expressed as following:

\[ L_A = 10\log \frac{P_i}{P_R} = L_{bf} - A \quad dB \quad \text{(18)} \]

Thus the power received by the two receiving antennas is as following:

\[ P_{R1} = \frac{P_i}{10^{L_{bf1}-A_i}} \quad \text{(19)} \]
\[ P_{R2} = \frac{P_i}{10^{10 - A_2}} \] (20)

Put \( P_{R1} = P_{INA} \), \( P_{R2} = P_{INA} \) into Equation (2), the output voltage amplitude differential of AD8302 meets the following calculation:

\[
V_{MAG} = \left( R_F I_{SLP} / 20 \right) \left( \frac{P_i}{10^{10 - A_2}} - \frac{P_i}{10^{10 - A_1}} \right) + V_{CP} \] (21)

When blood volume changes, the effect of L2 is stronger than L1 due to the L2 pathway is longer than that of L1. The amplitude differential factor is as following:

\[
\left( \frac{P_i}{10^{10 - A_2}} - \frac{P_i}{10^{10 - A_1}} \right) \] (22)

\( V_{MAG} \) changes with the amplitude differential factor, according to which blood volume change can be calculated.

**Conclusion**

Based on nowadays advanced electronic technology, it is realized that the measurement of synchronous measurement becoming realized. This instrument can quickly measure parameters such as hardness, length and blood supply.

Next, we will combine the EEG information to more accurately identify organic and psychological ED.

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