Abstract — Fetal monitors are bedside units that consist of a monitoring unit, cables, and electrodes. They are designed to measure, record, and display FHR, uterine contractions, and/or maternal blood pressure and heart rate before and during childbirth. These monitors may sense FHR and uterine contraction indirectly through the mother’s abdomen and/or directly by placing an electrode on the fetal scalp (or other exposed skin surface) and measuring the change in pressure within the uterus. Antepartum fetal monitors are typically used in physician’s offices and clinics long before the beginning of labor. Most hospital-based monitors have additional capabilities, including fetal and maternal ECG recording. Continuous electronic FHR monitoring can be performed indirectly, by applying an ultrasound transducer to the mother’s abdomen, or directly, by attaching an electrode assembly to the fetus after rupture of the amniotic membranes. Uterine contractions can be recorded along with FHR by placing a pressure transducer on the mother’s abdomen or by directly measuring the change in pressure in the uterus with a catheter.

KEYWORDS: Cardiotocographs; fetal electrocardiogram (ECG) monitors; fetal heart rate monitors; ultrasonic fetal monitors; Monitor, cardiac, fetal; Monitor, heart valve movement, fetal, ultrasonic; Monitor, phonocardiographic.

I- INTRODUCTION

The Fetal monitor works on the principle of Doppler effect. Low intensity ultrasound frequency is beamed into the body from the small transducer probe. The beam is reflected back with slight change in frequency due to movement of fetal heart, blood particles or other moving organs. The reflected signal is received by the instrument, amplified and processed electronically to produce audible beeps on the built-in speaker or external earphone. A Doppler fetal monitor or Doppler fetal heart rate monitor is a hand-held ultrasound transducer used to detect the heartbeat of a fetus for prenatal care. It uses the Doppler effect to provide an audible simulation of the heartbeat. Some models also display the heart rate in beats per minute. Use of this monitor is sometimes known as Doppler auscultation. Doppler fetal monitors are commonly referred to simply as "Dopplers". Doppler fetal monitors provide information about the fetus similar to that provided by a fetal stethoscope. One advantage of the Doppler fetal monitor over a (purely acoustic) fetal stethoscope is the electronic audio output, which allows people other than the user to hear the heartbeat. One disadvantage is the greater complexity and cost and the lower reliability of an electronic device.

II- DESIGN OF DOPPLER FETAL HEART RATE MONITOR

A. Doppler Effects

When wave energy like sound or radio waves travels from two objects, the wavelength can seem to be changed if one or both of them are moving. This is called the Doppler effect.

The Doppler effect causes the received frequency of a source (how it is perceived when it gets to its destination) to differ from the sent frequency if there is motion that is increasing or decreasing the distance between the source and the receiver. This effect is readily observable as variation in the pitch of sound between a moving source and a stationary observer.

When the distance between the source and receiver of electromagnetic waves remains constant, the frequency waves is the same in both places. When the distance between the source and receiver of electromagnetic waves is increasing, the frequency of the received wave forms is lower than the frequency of the source wave form. When the distance is decreasing, the frequency of the received wave form will be higher than the source wave form. Generally, in classical physics, where the speeds of source and the receiver relative to the medium are lower than the velocity of waves in the medium, the relationship between observed frequency \( f \) and emitted frequency \( f_0 \) is given by:

\[
f = \frac{f_0}{1 + \frac{v_r}{C}} = \frac{f_0}{1 + \frac{v_r}{C}} \times f_0
\]

where

- \( C \) is the velocity of waves in the medium;
- \( v_r \) is the velocity of the receiver relative to the medium; positive if the receiver is moving towards the source (and negative in the other direction);
\( v_s \) - is the velocity of the source relative to the medium; positive if the source is moving away from the receiver (and negative in the other direction).

The frequency is decreased if either is moving away from the other.

The above formula assumes that the source is either directly approaching or receding from the observer. If the source approaches the observer at an angle (but still with a constant velocity), the observed frequency that is first heard is higher than the object's emitted frequency. Thereafter, there is a monotonic decrease in the observed frequency as it gets closer to the observer, through equality when it is coming from a direction perpendicular to the relative motion (and was emitted at the point of closest approach; but when the wave is received, the source and observer will no longer be at their closest), and a continued monotonic decrease as it recedes from the observer. When the observer is very close to the path of the object, the transition from high to low frequency is very abrupt. When the observer is far from the path of the object, the transition from high to low frequency is gradual.

If the speeds \( v_s \) and \( v_r \) are small compared to the speed of the wave, the relationship between observed frequency \( f \) and emitted frequency \( f_0 \) is approximately

\[
\begin{align*}
\text{Observed frequency} & \quad \text{Change in frequency} \\
\quad f = \left(1 + \frac{\Delta v}{c}\right) f_0 & \quad \Delta f = \frac{\Delta v}{c} f_0 \\
\text{where} & \quad \Delta f = f - f_0 \\
& \quad \Delta v = v_r - v_s
\end{align*}
\]

The above equation is the velocity of the receiver relative to the source. It is positive when the source and the receiver are moving towards each other.

### B. Doppler Fetal Heart Rate Monitor

A Doppler fetal heart rate monitor is a hand-held ultrasound transducer that uses the Doppler effect to provide an audible simulation of a heartbeat and display the number of beats per minute on a screen. The Doppler effect is the wavelength variation of any wave sent or received by a moving object. In this case, the source sends acoustic waves to the heart of a fetus inside the mother’s womb. Part of the energy bounces back. However, because the heart is beating, the bounced waves are affected by the Doppler effect. This changes their frequency. Therefore, with simple algorithms the fetal and mother’s heartbeats are detected separately because of the different frequencies of the mother’s and fetus’s heartbeats.

**Observed frequency**

\[
\begin{align*}
\quad f = \left(1 + \frac{\Delta v}{c}\right) f_0 & \quad \Delta f = \frac{\Delta v}{c} f_0 \\
\text{where} & \quad \Delta f = f - f_0 \\
& \quad \Delta v = v_r - v_s
\end{align*}
\]

### C. Types of Dopplers

Dopplers for home or hospital use differ in the following ways:

- **Manufacturer**: popular manufacturers are Newman Medical, Nicolet (purchased by Natus), Arjo-Huntleigh, and Summit Doppler (now Cooper Surgical).
- **Probe Type**: waterproof or not. Waterproof probes are used for water births.
- **Probe Frequency**: 2-MHz or 3-MHz probes. Most practitioners can find the heart rate with either probe. A 3-MHz probe is recommended to detect a heart rate in early pregnancy (8–10 weeks gestation). A 2-MHz probe is recommended for pregnant women who are overweight. Newer 5-MHz transvaginal probes aids in the detection of fetal heart tones (FHT) early in pregnancy (6–8 weeks) and for patients who have a retroverted uterus or throughout pregnancy for FHT detection for women who are obese.
- **Heart Rate Display**: some Dopplers automatically display the heart rate on a built-in LCD; for others the fetal heart rate must be counted and timed by the practitioner.

The generic use of the word "Sonicaid" for Doppler fetal monitors comes from the products of the UK company Sonicaid Ltd. Sonicaid products included the D205/206 portable fetal Dopplers and FM2/3/4 series of fetal monitors. The company was acquired by Oxford Instruments in 1987 to form Oxford Sonicaid. It was recently demonstrated that continuous Doppler enables the auscultation of valvular movements and blood flow sounds that are undetected during cardiac examination with a stethoscope in adults. The Doppler auscultation presented a sensitivity of 84% for the detection of aortic regurgitations while classic stethoscope auscultation presented a sensitivity of 58%. Moreover, Doppler...
auscultation was superior in the detection of impaired ventricular relaxation. Since the physics of Doppler auscultation and classic auscultation are different, it has been suggested that both methods could complement each other.

### III - HARDWARE DESIGN OF FETAL HEART RATE MONITOR

- **Ultrasonic Probe**

  The ultrasonic probe may consist of an oscillator (X1 in Figure 2 below) that generates an ultrasound frequency (for these applications, the range is 1–3 MHz) followed by an amplifier to condition the sine waveform in volts. This waveform is applied to the transmitter transducer to send vibrations through the body and bounce back when the density of the medium changes. Another transducer is used to receive the bounced vibrations and convert them to electrical signals. This signal is amplified using an instrumental amplifier and is sent to a band-pass filter. The filtered signal is sent to a phase-locked loop to generate a voltage signal, which depends on the frequency applied. For implementations of the instrumentation amplifier and band-pass filter

![Figure 2](image)

- **Electrical Protection**

  Any time an AC-powered medical device comes into contact with a patient, the system must be designed with electrical protection in mind. Electrical protection limits the current to a non-harmful range of 6–10 mA maximum avoiding the probability of electrical discharge. This also should provide isolation between the power source of the device and the sensor that is in contact with the person. In the transmitter ultrasound probe example (Figure 2) the resistor R3 limits the current to transformer T1. Transformer T2 provides isolation between the circuit and the patient’s body. Transformers T1 and T2 must have a 1:1 relationship, and should not be affected by the operational frequency of the transducers.

- **Signal Conditioning**

  Signal conditioning can be implemented using a band-pass filter to reject noise. Using an active filter, the signal can be conditioned to determine values. The signal at the output of the band-pass filter is sent to a phase-locked loop to generate a frequency-dependent voltage. The phase-locked loop must be configured so that the frequency of the look-in range matches the band-pass filter bandwidth. This signal is applied to an input of the analog-to-digital converter embedded on the microcontroller. The microcontroller is responsible for processing the information acquired according to an algorithm and displaying the data on an LCD screen. Freescale provides microcontrollers with embedded LCD controllers such as the MC9S08LL, MC9S08LE, MC9S08LA, and MC9S08LC families. Ultra-low-power MCUs with LC drivers are in the LL family.

- **Transmitter Ultrasonic Probe Example**

- **Receiver Ultrasonic Probe Example**

![Figure 3](image)
### Ultrasound Probe Elements Block Diagram

- Oscillator
- Amplifier
- Current limiter
- Transducer
- Receiver/transducer
- Signal conditioning
- Electrical protection
- Fétique

### Types of electronic components & tools for common fetal heart rate monitor

- **Microcontrollers**
  - **RS08LA**: 8-bit with LCD Driver LA MCUs
    - 8-bit MCU, LCD driver
  - **S08JM**: 8-bit USB Cost-Effective JM MCUs
    - 8-bit MCU, USB
  - **S08LL**: 8-bit Ultra-Low-Power Segment LCD LL MCUs
    - 8-bit low-power MCU, segment LCD control
  - **S08QE**: 8-bit Flexis Low-Power QE MCUs
    - 8-bit ultra-low-power MCU

- **Power Management**
  - **MC34712**: 3.0 A 1.0 MHz Fully Integrated DDR Switch-Mode Power Supply
  - **MC34713**: 5.0 A 1.0 MHz Fully Integrated Single Switch-Mode Power Supply
  - **MC34716**: 1.0 MHz Dual Switch-Mode DDR Power Supply
  - **MC34717**: 5.0 A 1.0 MHz Fully Integrated Dual Switch-Mode Power Supply

- **Products**
  - **Features**
  - **MCF51QE**: Flexis 32-bit ColdFire V1 Microcontroller
    - 32-bit ultra-low-power MCU, 256K flash, USB
  - **VF3xx**: Hybrid family with ARM® Cortex™-A5, 1.5MB SRAM, LCD, security, 2x Ethernet, L2 switch
    - ARM Cortex-A5 266MHz, 1.5M SRAM, Display, dual 10/100 ETH, dual CAN, PMU, <1W

- **Wireless Communications**
  - Keypad or Touch Screen
  - **MPR121**: Proximity Capacitive Touch Sensor Controller
    - 12-pad touch sensor
  - **MPR03x**: Proximity Capacitive Touch Sensor Controller
    - 2 or 3-pad touch sensor
  - **TSSMCU**: Xtrinsic Touch-Sensing for MCUs
    - Xtrinsic Touch-Sensing software, converts S08 and ColdFire V1 MCUs into touch sensors
  - **CRTOUCH**: Xtrinsic Touch-Sensing Platform – a Ready Play Solution
    - Resistive screen controller with basic gesture recognition, and up to four capacitive touch-sensing electrodes
  - **Pressure Sensors**
    - **MPX2300DT1**: 0 to 40kPa, Differential, Pressure Sensor Medical Grade
      - Compensated pressure sensor
  - **Power Management**
    - **MC34712**: 3.0 A 1.0 MHz Fully Integrated DDR Switch-Mode Power Supply
    - Li-Ion battery charger, DDR switch-mode power supply (3.0A, 1MHz)
    - **MC34713**: 5.0 A 1.0 MHz Fully Integrated Single Switch-Mode Power Supply
      - Li-Ion battery charger, single switch-mode power supply (5A, 1MHz)
    - **MC34716**: 1.0 MHz Dual Switch-Mode DDR Power Supply
      - Li-Ion battery charger, dual switch-mode DDR power supply (5A, 1Mhz)
    - **MC34717**: 5.0 A 1.0 MHz Fully Integrated Dual Switch-Mode Power Supply
      - Li-Ion battery charger, dual switch-mode power supply (5A, 3.3V)
MC13211: 2.4 GHz 802.15.4 RF and 8-bit HCS08 MCU with 16KB Flash, 1KB RAM

| 2.4 GHz low-cost system in package (SiP) | • Touch U/I suited for sterile handheld monitors
| • Cost-effective, amplified, small form factor sensors with high sensitivity
| • Integrated analog portfolio that enables maximum battery life with advanced PMICs

MC13233: 2.4 GHz 802.15.4 RF and 8-bit HCS08 MCU with up to 82KB Flash, 5KB RAM

Additional Freescale Devices

This table describes additional Freescale devices that can be used for fetal heart rate monitor applications, as well as application notes.

Advantages some of this products

- 8-bit MCUs offer low-power consumption to enable longer battery life
- S08LL MCU provides additional superior LCD controller IP
- Dedicated medical peripherals and healthcare connectivity stacks
- USB, IEEE® 802.15.4 and ZigBee® technology solutions for wireless interfaces
- Pressure sensors packaged specifically for medical applications
- High end MPIs, video and graphics acceleration

IV- THE USAGE OF FETAL HEART RATE MONITOR (INTERNAL & EXTERNAL)

![figure a 5](image)

Electronic fetal heart monitoring is done to keep track of the heart rate of the baby (fetus) and the strength and duration of the contractions of the uterus. The baby's heart rate is a good way to tell whether the baby is doing well or may have some problems.

Two types of monitoring-external and internal-can be done.

A. External Usage

External monitoring can be done by listening to the baby's heartbeat with a special stethoscope. More often, external monitoring is done using two flat devices (sensors) held in place with elastic belts on the belly. One sensor uses reflected sound waves (ultrasound) to keep track of the baby's heart rate. The other sensor measures the duration of the contractions. The sensors are connected to a machine that records the information. The baby's heartbeat may be heard as a beeping sound or printed out on a chart. The frequency and duration of the uterine contractions are usually printed out on a chart.
External monitoring is used for a nonstress test, which records the baby's heart rate while the baby is moving and not moving. A nonstress test may be combined with a fetal ultrasound to evaluate the amount of the amniotic fluid.

External monitoring is also done for a contraction stress test, which records changes in the baby's heart rate when the mother's have uterine contractions. It may be done to check on the baby's health if the baby does not move enough during a nonstress test. It may help predict whether the baby can handle the stress of labor and vaginal delivery.

Sometimes external monitoring is done remotely (called telemetry), without the needing to be connected by wires to a machine. At some hospitals, the sensors can send the information about the baby's heart rate and the uterine contractions to a remote monitor, usually at a nurse's station. Remote monitoring allows the mother's to walk around freely.

External fetal heart monitoring is done to:

- Keep track of the baby's heart rate.
- Measure how often the mother's have a contraction and how long the contractions last during labor and delivery.
- Find out whether the mother’s are having preterm labor
- Check on the baby's health if problems are suspected. External fetal heart monitoring will be done during a nonstress test to check the baby's heart rate while at rest and while moving. If the baby does not move during this test, more testing will be needed.
- Check on the placenta to make sure that it is giving the baby enough oxygen. A contraction stress test that shows that the baby is not getting enough oxygen helps the doctor make decisions about the safest delivery method. If the test shows that the baby may be in danger, the doctor may recommend starting (inducing) labor early or may talk to the mother’s about doing a cesarean section (C-section).
- Check the baby’s health if the baby has not been growing normally (delayed fetal growth) or if the mother’s have diabetes, high blood pressure (hypertension), or are over 41 weeks pregnant.

External monitoring can be done any time after 20 weeks of pregnancy. Internal monitoring is used only when the mother’s are in labor and the amniotic sac has broken. If internal monitoring is needed and the amniotic sac has not broken, the doctor may break the sac to begin the test. Sometimes a combination of internal and external monitoring is done by measuring the baby's heart rate with an internal sensor and measuring the contractions with an external sensor. For external monitoring, the mother’s will usually lie on a table on the back or left side. Two belts with sensors attached will be placed around the belly. One belt holds the sensor that keeps track of the baby's heart rate, while the other measures the timing and strength of the uterine contractions. Gel may be applied to provide good contact between the heart rate sensors and the skin. The sensors are attached with wires to a recording device that can indicate or print out a record of the baby's heart rate as well as the strength and duration of uterine contractions. The position of the heart rate monitor may be changed periodically to adjust to the movement of the baby.

For a nonstress test, the sensors are placed on the belly. The mother’s may be asked to push a button on the machine every time the baby moves or the mother’s have a contraction. The baby's heart rate is recorded and compared to the record of movement or the contractions. This test usually lasts about 30 minutes.

For a contraction stress test, the sensors are placed on the belly. After about 20 minutes of monitoring, uterine contractions are started (induced). To start contractions, the mother’s may be instructed to stimulate the nipples or the mother’s may be given a medication called oxytocin (such as Pitocin) in a vein (intravenous, or IV). If oxytocin is given, it will be increased gradually until the mother’s have 3 contractions in 10 minutes. Changes in the baby's heart rate in response to the contractions are measured.

B. Internal Usage

Internal monitoring can be done only after the cervix has dilated to at least 2 centimeters (cm) and the amniotic sac has ruptured. Once started, internal monitoring is done continuously.

For internal monitoring, a sensor is attached to the thigh with a strap. A thin wire (electrode) from the sensor is inserted through the vagina and cervix into the uterus. The electrode is then attached to the baby's scalp. The baby's heartbeat may be heard as a beeping sound or printed out on a chart. Internal monitoring does not use reflected sound waves (ultrasound) for monitoring.
A small tube that measures uterine contractions may be placed in the uterus next to the baby. The strength and timing of the uterine contractions is usually printed out on a chart. Internal monitoring is more accurate than external monitoring for keeping track of the baby's heart rate and the contractions.

Internal fetal heart monitoring is done to:

- Find out if the stress of labor is threatening the baby's health.
- Measure the strength and duration of the labor contractions.

For internal monitoring, the mother's will usually lie on a table on the back or left side. A thin wire (electrode) will be guided through the vagina and cervix and attached to the baby's scalp. A small tube is also inserted through the vagina to connect a device that monitors the contractions inside the uterus. A belt is placed around the upper leg to keep the monitor in place. The electrode and the tube are attached with wires to a recording device that can indicate or print out a record of the baby's heart rate as well as the strength and duration of the uterine contractions.

V- SIDE EFFECTS OF DOPPLER HEART RATE MONITOR

Home Fetal Heart Rate Monitors: A Warning
The doctors involved with these cases warn that home Doppler device fetal heart monitors should only be used for ‘entertainment’ purposes. Understanding the sounds heard on a fetal heart rate monitor takes training and experience. People who do not have this training may mistakenly interpret the sounds of blood flow through the placenta or the mother's pulse as a healthy fetal heartbeat.

The doctors further advise women to trust their own instincts in regards to fetal movement and seek medical assistance when they are concerned there is a problem.

Currently, neither the most effective method of FHR monitoring nor the specific frequency or duration of monitoring to ensure optimal perinatal outcome has been identified by a significant body of scientific evidence. With the advent and liberal use of electronic FHR monitoring in the 1970s, there was great hope that intrapartum fetal death and morbidity associated with intrapartum asphyxia could be virtually eliminated. Retrospective studies of electronic FHR monitoring in both high- and low-risk populations were encouraging. A review of 11 studies including almost 40,000 electronically monitored patients and nearly 100,000 historical controls suggested a reduction in the intrapartum fetal death rate from 1.76/1,000 births in controls to 0.54/1,000 births in monitored patient. Similar reductions in neonatal death rates were also observed. Subsequently, seven randomized, controlled trials have compared continuous electronic FHR monitoring with intermittent auscultation in both high- and low-risk patients; no differences in intrapartum fetal death rates were found. It is significant that the intermittent auscultation groups in all but one of the seven studies had a dedicated 1:1 nurse-to-patient ratio. Nurses auscultated the FHR at least every 15 minutes in the first stage of labor and every 5 minutes in the second stage. If only the results of the studies with this intensity of FHR auscultation are included, the intrapartum fetal death rate in auscultated women was only 0.5/1,000. This rate is nearly identical to those seen with electronic FHR monitoring in both prospective, randomized, controlled trials and retrospective, controlled studies. In contrast, the most recently published random- ized, controlled trial did show a significant reduction in perinatal deaths due to asphyxia in the electronically monitored group. It is not clear why this single study is so discordant with the others, but it does provide some promise that further studies may yet elucidate the real value of electronic FHR monitoring.

Likewise, a substantial body of evidence disproves the hypothesis that electronic fetal monitoring would reduce long-term neurologic impairment and cerebral palsy in newborns so monitored. Electronic FHR monitoring has been no more effective in reducing the rates of low Apgar scores at birth and long-term neurologic morbidity than has intensive intrapartum auscultative monitoring (as described here). One study did suggest that electronic FHR monitoring may decrease the rate of seizures in the newborn; however, this reduction did not persist into late childhood. On the other hand, another study showed a significant increase in cerebral palsy among premature infants monitored electronically during labor. The primary risk of electronic FHR monitoring is a potential increase in the cesarean delivery rate. This effect has been observed in both retrospective trials and the majority of prospective, randomized, controlled trials. More accurate interpretation of FHR monitoring, the use of fetal scalp blood pH monitoring, and possibly, the use of acoustic or scalp stimulation to elicit FHR accelerations can lead to more precise diagnosis of the condition of the fetus and, by inference, may lead to a decrease in the cesarean delivery rate. The use of amnioinfusion has also been shown in randomized, controlled trials to lower the cesarean delivery rate for those patients with FHR patterns consistent with umbilical cord compression.

VI- PROS & CONS OF USING FETAL DOPPLERS & HEARTBEAT MONITORS TO TRACK THE BABY’S GROWTH AT HOME
A. Pros Of Using A Fetal Doppler

- Gives peace of mind, especially in cases of high-risk pregnancies.
- If the mother’s are concerned about the baby not being active, the mother’s can check the heartbeat.
- Fetal dopplers can provide a unique bonding experience with the baby before birth.
- Monitoring an unborn child with a fetal doppler has no negative side effects.

B. Cons Of Using A Fetal Doppler

- They are not always reliable and can cause added anxiety.
- Doctors worry that using a monitor may cause parents to ignore possible signs of distress.
- Some parents will use the monitor for hours on end when it is recommended by the FDA to use it only in moderation.

VII- RESULTS ON USING FETAL HEART RATE MONITOR

Electronic fetal heart monitoring is done during pregnancy, labor, and delivery to keep track of the heart rate of the baby (fetus) and the strength and duration of the contractions of the uterus. The results of electronic fetal heart monitoring are usually available immediately.

<table>
<thead>
<tr>
<th>Electronic fetal monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Normal:</strong></td>
</tr>
<tr>
<td>The baby's heart rate is between 110 to 160 beats per minute.</td>
</tr>
<tr>
<td>The baby's heart rate increases (accelerates) when he or she moves and when the uterus contracts.</td>
</tr>
<tr>
<td>The baby's heart rate drops during a contraction but rapidly returns to normal after the contraction is over.</td>
</tr>
<tr>
<td>Uterine contractions during labor are strong and regular.</td>
</tr>
<tr>
<td><strong>Abnormal:</strong></td>
</tr>
<tr>
<td>The baby's heart rate is less than 110 beats per minute.</td>
</tr>
<tr>
<td>The baby's heart rate is more than 160 beats per minute.</td>
</tr>
<tr>
<td>During a nonstress test, the baby's heart rate does not increase by 15 beats per minute or drops far below its baseline rate (deceleration) after he or she moves.</td>
</tr>
<tr>
<td>During a contraction stress test, the baby's heart rate drops far below its baseline rate after each uterine contraction.</td>
</tr>
<tr>
<td>Uterine contractions are weak or irregular during labor.</td>
</tr>
</tbody>
</table>

REFERENCES


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