# A low-cost and portable stand alone system for permittivity measurement

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**Abstract**

This paper presents the design and development of a portable instrument that detect adulteration in Indian gasoline by measuring its electrical characteristic. We intend to measure percentage ethanol in Indian Gasoline sample by measuring permittivity of the mixture. An ARM processor based instrument is developed using LPC-2148 microcontroller, frequency synthesizer, high frequency (HF) amplifier, peak detector, and microwave ring resonator as a sensor operating at 2-2.5 GHz. The instrument is calibrated for percentage ethanol measurement in Indian gasoline along with temperature compensation for better analysis. Our aim was to develop a low cost portable accurate and rugged instrument which can be used in field of permittivity evaluation.

*Keywords:* Gasoline adulteration, Portable embedded system, Microwave sensors

## 1. Introduction

In the petroleum refinery industry, there is increasing demand for determination of product quality. Standard gasoline is a dielectric liquid mixture with about thirty different hydrocarbons. Gasoline is a mixture of standard gasoline and dehydrated ethanol, produced from sugar cane. The amount of ethanol added to the gasoline is a function of the international crude oil price, sugar cane production and the price of sugar in the international market. The gasoline adulteration is done by adding a higher concentration of ethanol, or using hydrated ethanol, or adding foreign solvents. The vehicle engines are modified according to the ethanol percentage in petrol. Most metal components in automobile fuel systems will corrode or rust in the presence of water, air or acidic compounds, and the addition of ethanol increases petrol's ability to hold water. Several studies have shown that the vehicle tanks and fuel system components do not corrode until the ethanol percentage goes up to 10%. ethanol, like other renewable fuels, has a lower calorific value than petrol. This results in ethanol and petrol blends having a lower calorific value than that of neat petrol and thus increasing fuel consumption. For this purpose, we have considered finding percentage of ethanol in gasoline. In order to detect the percentage of impurity in the given sample, we have designed microwave resonators, which are used as sensors. Thus, our main aim is to design and develop portable instrument to calculate percentage of ethanol in Indian gasoline by measuring the permittivity of the mixture, and include temperature compensation for better analysis.

The rest of the article is organized as follows, section 2 presents design and fabrication of microwave resonator, embedded components selection, and implementation of our stand alone system for finding adulteration in gasoline. Section 3 presents the experimental setup and some discussion regarding our stand alone system. Section 4 gives some concluding remarks.

## 2. Materials and methods

In this section, we first discuss the working principle of the microwave resonator and present its development and fabrication. We then present our stand alone system architecture and experimental setup.

### 2.1. Microwave resonator as a sensor

Dielectric measurements are an effective tool for extracting significant information related to the structure and to the quality-status of various materials. General aspects of petroleum quality are assessed by measurement of physical properties such as relative density, refractive index or viscosity or by pour point or oxidation stability. Several techniques are required for analysis because chemical composition of petroleum is very complex. We use perturbation principle for determining dielectric properties of the gasoline. Perturbation concept is based on the shift in resonant frequency $f_r$ and the change in absorption characteristics of a tuned resonator, due to insertion of a sample of target material. The perturbation technique is frequently used for measuring dielectric properties of several materials because of its simplicity, easy data reduction, accuracy, and high temperature capability. The technique is well suited to low dielectric loss materials. There are various permittivity evaluation techniques, such as, wave guide and coaxial transmission line method, open ended probe technique, free space transmission technique, microstrip transmission line, admittance cell methods and microwave resonators. We use microwave resonator for analyzing permittivity because it is simple for simulation, development and testing. It has less error due to air bubble contamination. It requires smaller sample size for testing and is cost effective method.

For a microwave resonator, at resonant frequencies, maximum energy transfer takes place. So, we get a peak in the transmission characteristics indicating maximum energy transfer. We transmit a radio frequency (RF) test signal to such a resonator, the reflected energy from the resonator is studied and resonator characteristics are deduced. There are two basic types of microwave resonator. If a microstrip line is formed as some closed loop on substrate then the microwave resonator is a ring resonator. Another type is $\lambda/2$ resonator in which microstrip line is left open or short circuited at both ends. The ring resonator is better in performance as it has less loss and has greater ability for storing microwave energy. Therefore, we designed a ring resonator centered at 2.45 Ghz in high frequency structural simulator (HFSS) and got it fabricated for our application. The dielectric constant of gasoline is expected to vary slightly in the RF range (up to 2.5 GHz)on the other hand the dielectric constant of ethanol varies strongly in this range, as ethanol is a polar liquid. Thus, our resonator can significantly detect presence of ethanol in gasoline. Fig. 1, shows the utilized microwave resonator as a sensor.

Figure 1: Fabricated ring resonator.

A resonator is a structure that has one natural frequency of oscillation, known as resonant frequency $f_r$. In a microwave resonator electromagnetic waves travel back and forth between reflecting points resulting in a standing wave pattern, where the energy pulsates between electric and magnetic fields. The size and shape of the structure and the dielectric and magnetic properties of the medium, where the microwaves propagate, determines $f_r$. The network analyzer is used to test and verify the fabricated resonator. It was found that the resonator transmits maximum power transfer at 2.44 GHz, thus verifying its accuracy after fabrication. Fig. 2, shows the setup of resonator connected to the network analyzer.

### 2.2. Resonator characteristics database

For finding out percentage of ethanol in gasoline we have generated a database of various microwave resonator characteristics. The characteristics considered are resonant frequency $f_r$, quality factor (Q-factor), bandwidth, loss, and permittivity. We included temperature variations while generating the database. Therefore, our stand alone system can work effectively between 0 to 30°C. For temperature control we used a cabinet incubator. The setup for database generation is as shown in the Fig. 3.

We took reading for gasoline samples containing 0%, 2%, 4%, 5% and 7% ethanol content. Fig. 4 shows the variation in resonant frequency due to the change in the temperature for gasoline samples with various percentage of ethanol. Maximum

Figure 2: Ring resonator connected to the network analyzer.

Figure 3: Ring resonator connected to the network analyzer inside a cabinet incubator.

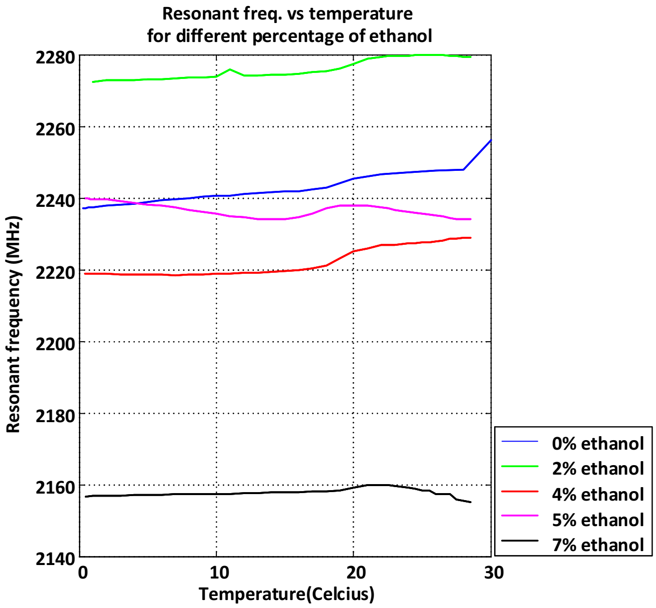


Figure 4: Variation in resonant frequency due to the change in the temperature for gasoline samples with various percentage of ethanol.

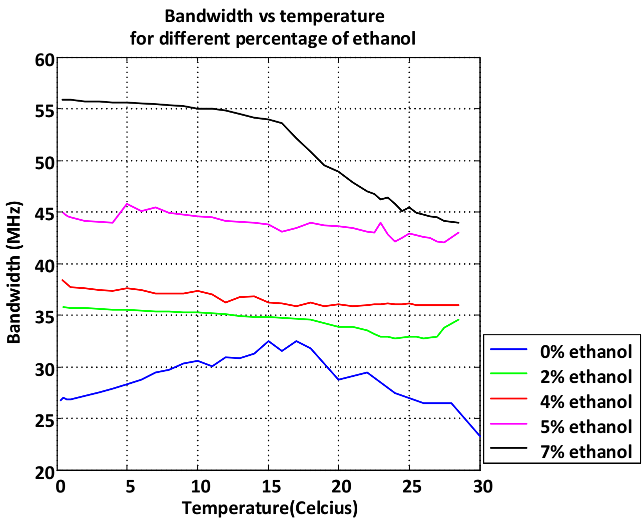


Figure 5: Variation in bandwidth due to the change in the temperature for gasoline samples with various percentage of ethanol.

resonant frequency is observed for gasoline having 0% ethanol blend. Since ethanol is a polar liquid, which absorbs RF energy, an increase in the percentage of ethanol will decrease the resonant frequency. Hence, the minimum resonant frequency is observed at 7% ethanol blend. Figure 5 shows the variation in bandwidth along with the change in the temperature for various percentage of ethanol blends. It is observed that maximum bandwidth is observed for gasoline having 7% ethanol blend. The minimum bandwidth is observed for 0% ethanol blend. Fig. 6 shows variation in the Q-factor along with the changes in the temperature for various percentage of ethanol. It is observed that maximum Q-factor is obtained at 0% ethanol blend. Since, $Q = f_r/Bandwidth$ ,Q-factor varies as a function of resonant frequency. Thus, Q-factor decreases along with increase in percentage ethanol. Minimum Q-factor is observed at 7% ethanol blend. Fig.

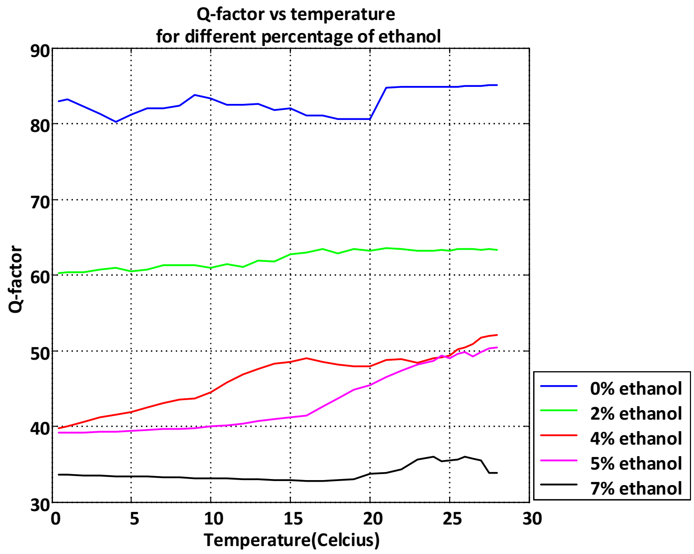


Figure 6: Variation in Q-factor due to the change in the temperature for gasoline samples with various percentage of ethanol.

7 shows variation in loss along with the changes in temperature for various percentage of ethanol blends. Minimum loss is observed at 0% ethanol blend. Losses vary directly with respect to percentage of ethanol. Therefore, 7% ethanol blend has maximum loss.

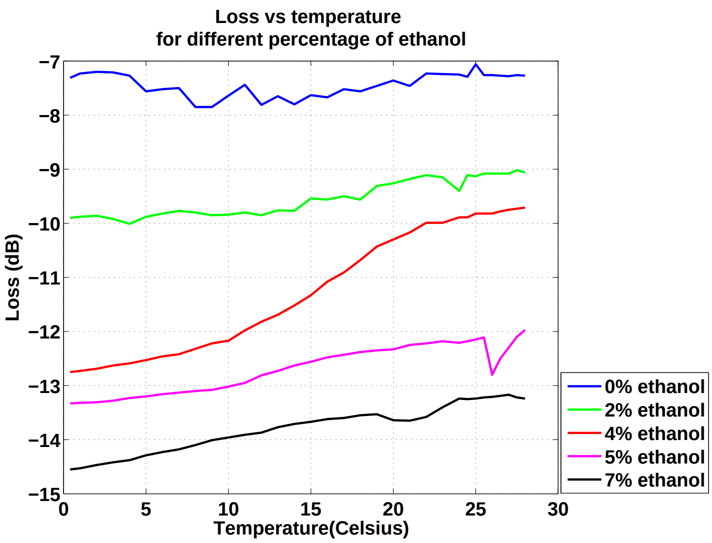


Figure 7: Variation in loss due to the change in the temperature for gasoline samples with various percentage of ethanol.

These database values are later fed to LPC2148 microcontroller by training an artificial neural network. The neural network was trained using back propagation algorithm and was initialized for a predetermined sequence of temperature, Q-factor, resonant frequency, bandwidth and loss. After 6000 epochs, i.e., number of iterations it was found that neural network correctness is 98.91%. This database is used for comparison and finding percentage of ethanol in an unknown sample of gasoline.

### *2.3. System block diagram and working*

Fig. 8, shows the block diagram of our stand alone system. The microcontroller controls the fre-

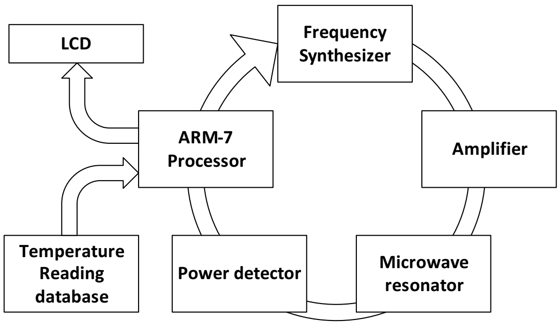


Figure 8: System block diagram.

quency synthesizer to generate a test frequency signal. This signal is amplified and fed to the sensor (Microwave resonator). The sensor cavity is filled by the gasoline sample for which percentage of ethanol is to be found. The output power of the sensor is traced by a peak detector. The peak detector maps the input power to the respective output voltages. The analog output from the peak detector will be converted to digital by the on board ADC of the microcontroller, which is stored for further processing. The microcontroller changes the input to the frequency synthesizer to generate next test frequency. After sweeping through all test frequencies, i.e., 2-2.5 GHz, the microcontroller will trace the migration of cavity resonance from the stored database of the pure sample. Then from the traced curve we will be able to find the resonant frequency, bandwidth and Q-factor. Thus with the help of these characteristics we can find the percentage of ethanol change in petrol.

### *2.4. Embedded component selection and specifications*

We discuss the selection of embedded components and their specifications as follows.

### 2.4.1. Frequency synthesizer selection

For our application we required frequency synthesizer, which would generate test signals from 2-2.5 GHz. We compared various frequency synthesizers, such as SA8026 by Philips Semiconductors, LMX2470 and LMX2485 by National Semiconductor, ADF4351 and ADF4350 by Analog Devices. After comparing the system requirements with the available synthesizers we selected ADF4350 by Analog Devices.

The frequency synthesizer features are as given:

- Output frequency range: 137.5 - 4400 MHz.
- Fractional-N and integer-N synthesizer.
- Low phase noise.
- Output divide-by -1, -2, -4, -8, and -16.
- Typical RMS jitter: $< 0.4$.
- Power supply: 3.0 - 3.6 V.
- Logic compatibility: 1.8 V.
- 3-wire Serial peripheral interface (SPI).

### 2.4.2. Power detector selection

We were interested in dynamic range of 0 to -60 dB. We wanted a power detector with log scale and which could detect power of high frequency signals. We considered many power detectors, such as, LTC5533, LTC5535, LTC5570, LTC5538, AD8364, AD8361, etc. After comparing the system requirements and cost we selected AD8364 power detector by Analog Devices.

The power detector features are as given:

- RMS measurement.
- Dual-channel and channel difference output ports.
- Integrated accurately scaled temperature sensor.
- Wide dynamic range of 60 dB.
- 0.5 dB temperature linear-in-dB response.

### 2.5. Microcontroller selection

We looked for a microcontroller with low power consumption as our goal is to implement a portable stand alone system. We considered ATMEGA-32 by AVR, 16F87X by PIC, 8051 by Intel, and LPC-2148 by ARM. We selected LPC-2148 by ARM as it had highest on board memory, highest oscillator frequency and low power consumption.

The features for LPC-2148 are as follows:

- 32-bit processor.
- High operating frequency of 60MHz.
- 40 kb of on-chip static RAM and 512 kb of on-chip flash program memory.
- Multiple user interface like UART, SPI, SSI, I2C, USB.
- Up to 45 of 5 V tolerant fast general purpose I/O pins.
- In-built 10-bit ADC with conversion time as low as 2.44 $\mu$-sec.
- Single 10-bit D/A converter.

## 3. Experimental setup and discussions

Fig. 9 shows the experimental setup of our portable stand alone system. A 3.3-V power supply is used. The experimental setup has the same design flow of the block diagram. The percentage of ethanol content is displayed using LCD, which is embedded on the LPC-2148 microcontroller board.

### 3.1. Uncertainty Analysis

The factors that affect the accuracy of the measurement of percent ethanol :

- We have to consider the air contamination and its effects on the change in the response of the microwave resonator.
- We are changing frequency from 2 GHz to 2.5 GHz in steps of 100 kHz. Thus we have to consider the quantization error due to the step of 100 kHz.
- The exact percentage of ethanol used in the gasoline sample is unknown. So petrol samples tested by the laboratories need to be used.

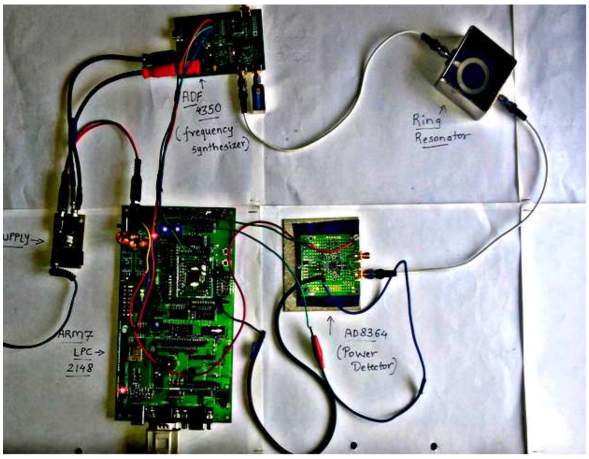


Figure 9: Experimental setup of our stand alone system.

### 3.2. Cost estimation

Previous approach for permittivity evalaution required a network analyzer, a personal computer with LabVIEW software installed. The resonator was connected to the network analyzer. The characteristics like resonant frequency, bandwidth, Q-factor and loss were computed after transferring the data to computer using LabVIEW software. Then the permittivity evaluation was done on the computer. Table 1 gives the cost estimation of this approach.

Table 1: Estimated cost of development for our stand alone system

| Item | model | Cost(INR) |
|---|---|---|
| Network analyzer | Agilent-8714ET | 7,00,000 |
| LabVIEW | version 8.5 | 1,20,000 |
| Personal computer | 1GB-RAM | 25,000 |
| Resonator | Ring resonator | 5,000 |
| | Total | 8,50,000 |

By making a portable stand alone system, we have made a considerable difference in cost. The table 2 gives the cost estimation of our stand alone system for permittivity evalutaion. Therefore, we have reduced the cost estimation by approximately 97%.

## 4. Conclusion

Ethanol addition in gasoline has its advantages and disadvantages. The amount of ethanol added in gasoline needs strict monitoring. There are many methods to deter mine amount of ethanol in petrol like gas chromatography, distillation, evaporation techniques etc. In this paper, we have developed an instrument to determine percentage of ethanol in gasoline using the frequency synthesizer ADF4350, power detector AD8364, LPC2148 microcontroller, and microwave ring resonator. This gives everyone a portable, low cost, compact and accurate alternative to measure percentage of ethanol in given gasoline sample. Our instrument is tested for multiple gasoline blend samples and is found to work accurately.

Table 2: Estimated cost of development for our stand alone system

| Item | model | Cost(INR) |
|---|---|---|
| microcontroller | LPC-2148 | 2,000 |
| Frequency synthesizer | ADF-4350 | 13,000 |
| Peak detector | AD-8364 | 5,000 |
| HF connectors | - | 1,000 |
| Resonator | Ring resonator | 5,000 |
| | Total | 26,000 |