Development Of
Characteristic Impedance Meter

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Abstract – **The paper describes the development of characteristic impedance meter. This is the first step towards automization of measurement of characteristic impedance of high frequency signal cables and connectors in Fast breeder reactors.**

***Index Terms*—Cable, impedance, connector. For a list of suggested keywords, send a blank e-mail to sivarama@igcar.gov.in**

1. INTRODUCTION

The paper is on the “DEVELOMENT OF CHARACTERISTIC IMPEDANCE METER”. The work is to design the scheme & circuit for the meter and program it to display the characteristic impedance value of the cable connected to the terminals of the meter, especially in the light of non availability of meter for direct measurement of characteristic impedance of cables. Circuit is designed keeping in view of various options the user should be provided, like reset, test mode, voltage and frequency selection range etc. The paper details the simulation studies. A prototype is being developed based on the study.

1.1 SIGNIFICANCE OF CHARACTERISTIC IMPEDANCE OF A CABLE:

Signal transmission at high frequencies is lot different to that at low frequencies.

The voltage at each point in a low frequency signal carrying wire can be considered to be constant and the resistance to be zero. In case of high frequency signal transmission, the wave nature of the signal is to be considered. Any media that supports high frequency signal transmission has characteristic impedance associated with it. Improper termination of such high frequency signal carrying cable causes reflections.
These reflections are due to mismatch of impedance between the cable and the terminal and results in signal distortion. A parallel resistance equal to the characteristic impedance of the cable when connected at the termination of the cable can reduce the reflections to a great extent, almost to zero.

The characteristic impedance, Z_0, of a line is the input impedance of an infinite length of the line. Characteristic impedance is of prime importance for good transmission. For a cable with constant impedance the signal gets transmitted as it is, without any distortion. If the impedance value of the cable keeps varying, energy is reflected back and the signal gets distorted. For optimal signal quality, the goal is to keep the impedance of the cable constant as seen by the signal. Maximum power transfer occurs when the source has the same impedance as the load. Thus for sending signals over a line, the transmitting equipment must have the same characteristic impedance as the line to get the maximum signal into the line. At the other end of the line, the receiving equipment must also have the same impedance as the line to be able to get the maximum signal out of the line. Where impedances do not match, some of the signal is reflected back towards the source. In many cases this reflected signal causes problems and is therefore undesirable.

Whereas, if the cable is terminated in its matching characteristic impedance, it cannot be observed if the cable is infinitely long, the entire signal that is fed into the cable is taken by the cable and the load.

1.2 NEED FOR THE METER:

The high frequency signals can be of very low magnitude like the signals produced by the sensors that are used to monitor the reactor functioning. The cables delivering such signals must be properly terminated to avoid loss of information. Using the meter, the characteristic impedance of the cable can be found out. By knowing the characteristic impedance value from the meter, the cable can be checked if it is properly terminated or not. The meter will be very handy especially when dealing with no. of field cables.

1.3 METER DEVELOPMENT:

Maximum power transmission principle is used to develop the meter. The power delivered by the cable is maximum when the cable is connected to a resistance equal to the cable’s characteristic impedance value. A voltage controlled resistor is used in the circuit, whose value is varied until maximum power transmission is achieved and the corresponding resistance value is displayed as characteristic impedance value of the cable. A microcontroller is used to calculate the power transmitted and to control the other peripheral devices like LCD, DAC and ADC. Annexure 1 gives the details of characteristic impedance in general industrial applications.

2. CHARACTRISTIC IMPEDANCE VALUES:

The earliest viable long-distance electrical communications system was the telegraph and its introduction spawned a whole range of new studies, techniques and products intended to maximize its benefits and its efficiency. Characteristic impedance of the resulting transmission lines was 600 ohms. The characteristic impedance of a wire-pair transmission line, though a function of wire thickness, distance between the conductors and the permittivity of the insulation between the pair of wires, 600 ohms was widely adopted as the 'standard' for telecommunications systems and later broadcast studio installations. More modern multi-paired cables had characteristic impedance closer to 140 ohms. Given that characteristic-impedance only has significance where the cable distances are a significant fraction of the wavelengths of the signals being carried the cable runs in general didn't come close to the distances where characteristic impedance is an important factor. The introduction of digital technology, however, revived the importance of characteristic impedance as the cable now had to demonstrate a reliable and predictable performance at frequencies significantly beyond their analogue counterparts and are now operating with signal wavelengths closer to the run-lengths of the cables. Presently, 75 ohms coaxial are widely available in the market. The characteristic impedance of the cable often ranges from 50 to 300 ohms.

3. EXISTING METHODS FOR CHARACTERISTIC IMPEDANCE CALCULATION:

3.1 CHARACTERISTIC IMPEDANCE EQUATION IN DIFFERENT CASES:

In general, the characteristic impedance is a complex number with a resistive and reactive component. It is a function of the frequency of the applied signal, and is unrelated to length. At very high frequencies, the characteristic impedance value asymptotes to a fixed value which is resistive in nature. For example, coaxial cables have an impedance of 50 or 75 Ohms at high frequencies. Typically, twisted-pair telephone cables have an impedance of 100 Ohms above 1 MHz .

Lossless transmission: When R and G are negligibly small the transmission line is considered as a lossless structure. In this hypothetical case, the model depends only on the *L* and *C* elements which case the expression reduces to Z_0 = sqrt (L/C

For materials commonly used for cable insulation, G is small enough that it can be neglected when compared with 2ωC. At low frequencies, 2ωL is so small compared with R that it can be neglected. Therefore at low frequencies the following equation can be used:

Z_0=sqrt(R/2jωC

When ω is large enough, the two terms containing ω becomes so large that R and G may be neglected and the resultant equation is

Z_0=sqrt (2jωL/2jωC) =sqrt (L/C)

3.2 DIFFERENT METHODS TO CALCULATE CHARACTERISTIC IMPEDANCE VALUE:

a) High frequency measurements of Z_0 can be made by determining the velocity of propagation and capacitance of the cable or by reflectometry.

b) For twisted pair and coaxial cables, the resistance is determined by the diameter or weight of copper, the inductance is very small, and the shunt conductance is small. The major influence on characteristic impedance and other secondary coefficients is the capacitance. This is largely determined by the type of insulation (dielectric) used. Characteristic impedance, for high frequencies, can be stated in terms of the physical dimensions of the cable. These formulae apply to copper conductor cables.

The design formula for characteristic impedance of a single coaxial line is:

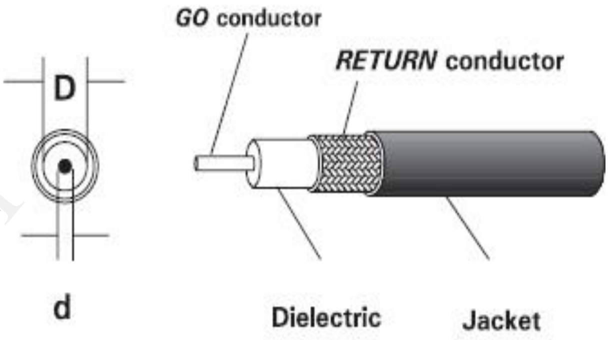


FIGURE I

$$Z_0 = (138 / \sqrt{E}) \times \log_{10} (D / d)$$

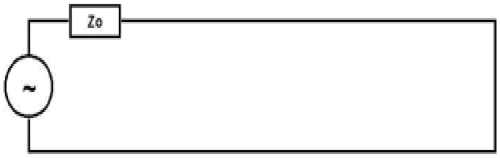
Where:

Z_0 = Characteristic impedance
E = Dielectric constant (air is 1.0)
D = Inside diameter of the "*return*" (outer) conductor (conductive metal tube or one or more braids)
d = Outside diameter of the "go" (inner) conductor of coaxial cable

These formulae show that the characteristic impedance of any cable is directly determined by the conductor sizes, the spacing between them and the type of insulation used. Any change in these will affect the characteristic impedance.

An approximate value of characteristic impedance can be estimated by the formula **Z_0=sqrt (Z_{0c}* Z_{sc})**

Where **Z_{0c}** is the impedance of the length of the cable with the far end open and **Z_{sc}** is when the far end is shorted.



In the above figure, cable of characteristic impedance zero is short circuited. All of the transmitted power is reflected back from the shorted end, because none of it is absorbed by the load. The impedance in this case is measured to be Z_{sc}.

The above figure the cable is left open. Even in this case all of the power is reflected because none can be absorbed by the load. The impedance in this case is measured to be Z_{oc}.

When the cable is terminated in a resistor of characteristic impedance value, the combination acts as an infinite length cable. The signals travel down the cable and are not reflected.

<u>Variation of characteristic impedance value with frequency</u>: The impedance of real lossy transmission line is not constant, but varies with frequency. At lower frequencies, ωL<<R and ωC< <G. hence Zo=sqrt(R/G). At higher frequencies ωL>>R and ωC>>G, then the characteristic impedance is given by Z_0=sqrt(L/C). Example: at 100 Hz , Z_0=900 ohms and in 30-40 Hz frequency range, 50 ohms.

The frequency dependence of characteristic impedance value should be considered while developing the meter.

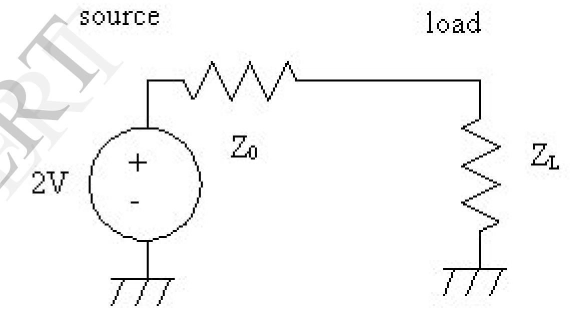
4. *DEVELOPMENT OF CHARACTERISTIC IMPEDANCE METER:*

The increasing use of electrical pulses in the transmission of data by cable has resulted in a need for a better understanding of the electrical characteristics of a cable. In the high frequency region, it is a relatively simple matter to make the load resistive equal to the cable impedance. However, pulses are a mixture of low and high frequencies, depending on their rise time, duration, and repetition rate. It is up to the system designer to determine whether the rising impedance of the cable at low frequencies is going to cause any difficulty and to take whatever design steps may be necessary to allow for it. When an alternating voltage is applied to the cable, with the far end open, a current will flow. With voltage (E) and current (I) measured in this circuit, impedance (Z) can be calculated (Z = E/I). The impedance will have some magnitude and some phase angle, which can be either positive or negative. However, if a portion of the cable is cut off and the measurement is repeated, a different impedance magnitude and a different phase angle will be observed. The characteristic impedance (Z_0) of a cable is independent of length, so obviously these measurements do not yield the characteristic impedance.

Many system specifications state the characteristic impedance value of the cables used. Any cable-maker's catalog will list the characteristic impedance values of most coaxial cables, which usually range from 50 to 95 ohms. The catalog may also refer to values of 100 to 200 ohms for certain shielded pairs which appear to be designed for special applications. But impedance information on the more common types of cables is not readily available to the cable user. This is because there are too many variations of the applications involved with the cables. The methods discussed earlier provide only an approximate value.

4.1 MAXIMUM POWER TRANSMISSION PRINCIPLE:

Consider the circuit shown below. A cable (Z_0) is connected to a power source with a resistance (Z_L) in series.

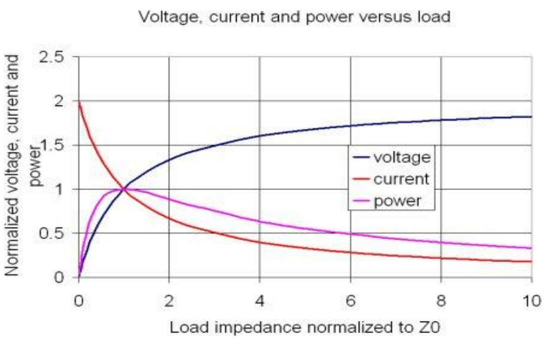


By Ohm's law and power definition, in the above circuit

$$V_L = 2V \frac{Z_L}{Z_L + Z_0}$$

$$P_L = \frac{V_L^2}{Z_L} = \frac{4V^2 Z_L}{(Z_L + Z_0)^2}$$

By differentiating the above equation for maximum power, the condition obtained is $\mathbf{Z_0 = Z_L}$.



From the above graph, power transmitted initially increases with increase in the value of Z_L, reaches maximum at Z_0 and decreases $Z_L > Z_0$.

There is no device in the market presently that can give the characteristic impedance value directly. Moreover, methods mentioned earlier either give unreliable values or approximate values.

So based on the maximum power transmission principle, a meter is to be developed to measure characteristic impedance value up to 5 % accuracy.

4.3 SPECIFICATIONS OF THE CHARACTERISTIC IMPEDANCE METER:

Basic accuracy:	+/-5%
Impedance range:	10 Ohms to 1000Ohms
Response time:	10s
Temperature of operation:	50^0C, 95%RH
Frequency selection:	1MHz, 10MHz, 100 MHz
Input connections:	provision to connect two leads of the cable to feed the input
Output connections:	provision to connect two leads of the cable to check the input
Reset button:	provision to clear the Screen and start next measurement
Test mode:	75 Ohm cable
Display:	LCD, alpha numeric with value and units,

"Frequency selections knob" is to select the frequency of the signal. The frequency can be set to either 1MHz or 10MHz or 100MHz.

"START" button to calculate the characteristic impedance value.

A "**TEST MODE**" is provided to check the proper functioning of the meter. A standard 75 Ohms cable is provided for the same.

"RESET" button is provided to clear the display and to start the calculation from the beginning.

4.4 WORKING OF THE METER:

As shown discussed earlier, maximum power is transmitted by the cable whenZ_0=Z_L. This principle is used to find the characteristic impedance of the cable.

A square wave signal is transmitted through the cable whose characteristic impedance value is to be determined. An op-amp square wave generator is used for this. The resistance of the Voltage Controlled Resistor (VCR) connected in series with the cable is varied to obtain maximum power transmission (V^2/R). The value of VCR at which maximum power transmission takes place is the characteristic impedance (Z_0) of the cable. Microcontroller is used to calculate the power values, find the maximum among them and to control the other peripheral devices. An LCD display is used to display the value.

4.5 COMPONENTS OF THE METER:

The basic components of the circuit of the meter include

a) Mains to DC conversion
b) OP AMP square wave generator
c) Voltage controlled variable resistor
d) Microcontroller
e) 12-bit Digital to Analog converter
f) LCD display
g) 8-bit Latch, switches, differentiator

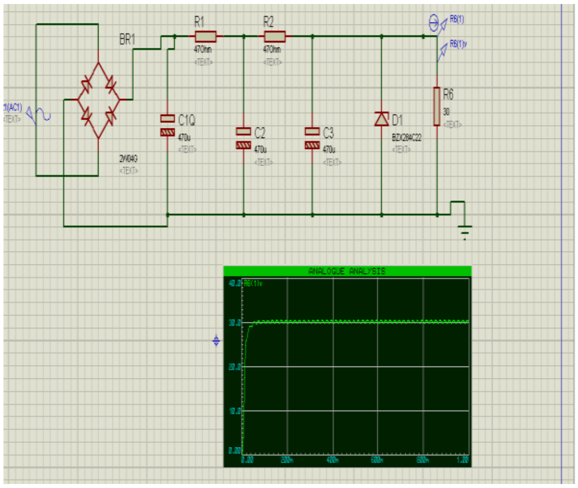
*4.5.1. **Simulation:***

In this paper, simulation software is used to simulate the circuit components. It is a layout package, which is used to create a PCB when the circuit has been designed. Schematic capture and interactive simulation software are used to create the circuit drawing and to test the circuit prior to building the real hardware. Mathematical circuit modeling system is done to get the real experience. Onscreen buttons and virtual signal sources, for example, provide inputs to the circuit. Output can be displayed on a voltage probe or on a virtual oscilloscope. With the microcontroller simulation, a program attached and debugged instantly.

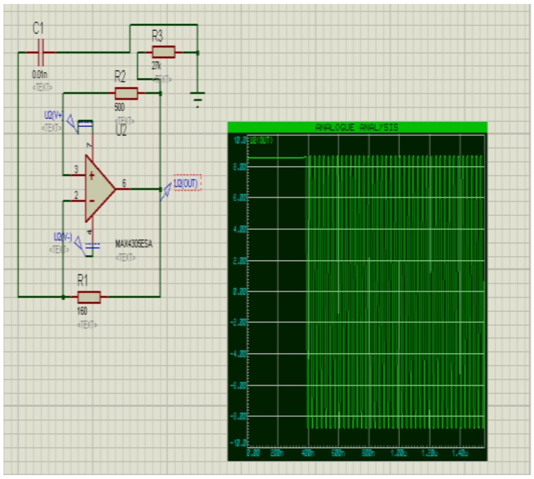
4.5.2 MAINS TO DC CONVERSION:

Power is supplied to the characteristic impedance meter from mains. Since all the components (op amp, Microcontroller, DAC, LCD) require DC source, mains AC should converted to DC. A bridge rectifier is used for rectification, RC combinations for filtering and a diode for regulating the signal. The output is 30V DC. DC-DC converters (30V to 5V,1V,15) to obtain the voltages required for op amp, microcontroller and other peripheral devices.

The following schematic shows mains to DC converting circuit:



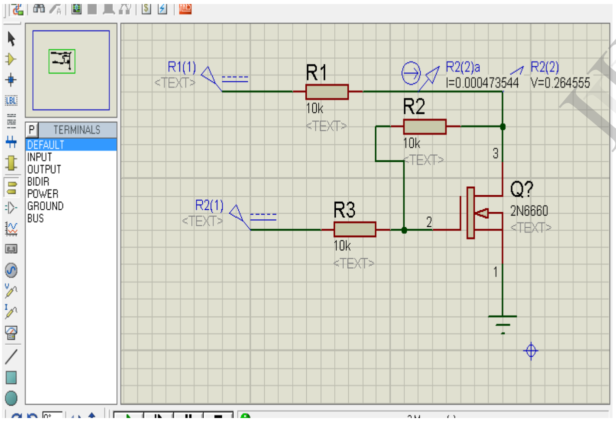
4.5.3 OP AMP SQUARE WAVE GENERATOR:



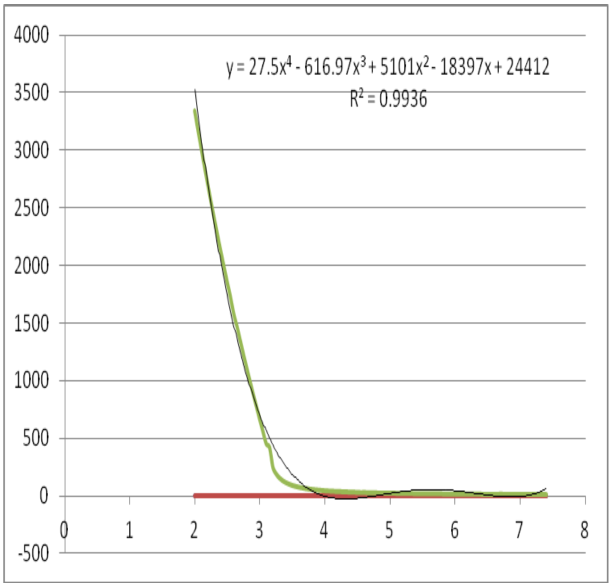
In the above circuit R1 and C1 determine the frequency. By changing the values of either R1 or C1, the output frequency can be changed.

Frequency=1/(2π*R1*C1)
By the above formula, keeping C1=0.01nF, R1 is changed.
1MHz output frequency is obtained for R1=16kΩ
10MHz output frequency is obtained for R1=1600Ω
100MHz output frequency, for R1=160Ω
To change the voltage amplitude of the output signal, the DC voltage 7 and 4 pins of the op-amp is changed accordingly.

4.5.4 n-channel enhancement MOSFET:



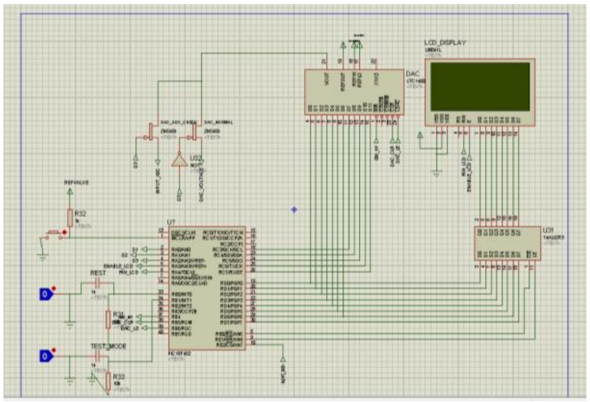
By changing the gate voltage (V_{GS})(R2(1) in the above schematic), the resistance across source drain of the MOSFET is varied. Below is the graph, showing the relation between the resistance(on y-axis) and V_{GS}(on x-axis).



The V_{GS} value is varied until maximum power is delivered across the cable, the corresponding resistance value is the characteristic impedance value.

4.5.5 MICROCONTROLLER, DAC AND LCD:

The below schematic shows the interfacing of microcontroller with LCD and DAC. PORT D is used to send data to LCD and DAC. Whenever DAC is to be selected, the 8-bit latch to LCD is enabled. Four PORTC pins are connected to DAC (total- 12 pins).

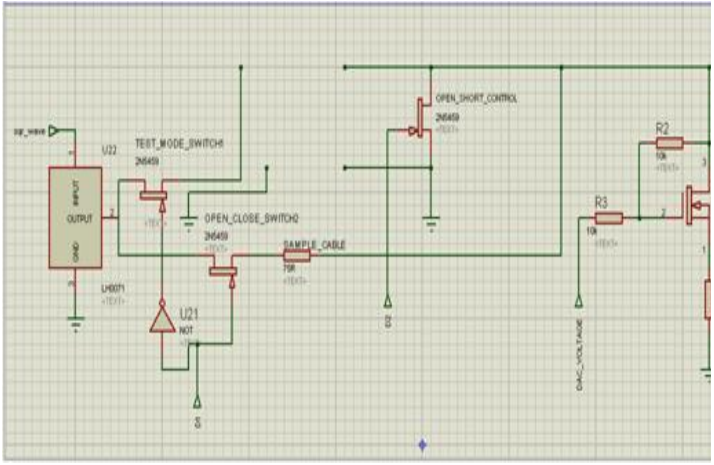


4.5.6 SWITCHES, DIFFERENTIATOR, TOGGLE KEYS, and PUSH BUTTON etc:

FET switches are used to a make or break the circuit. Digital output from microcontroller is used to control these switches. These are used in

a) Connecting DAC to ADC, in order to check their working at the time of power on. In other cases the output of DAC is connected to gate terminal of n-channel MOSFET.
b) Changing from normal mode to TEST MODE

Push button is used to RESET the meter. Toggle keys are used for hardware interrupts. As they produce level signals, differentiators are used to convert them to edge signals that can trigger interrupts in microcontroller. Four terminals are provided (two on each side)in the meter for the cable to be connected. The schematic shows the switch used to connect the sample cable in the test mode

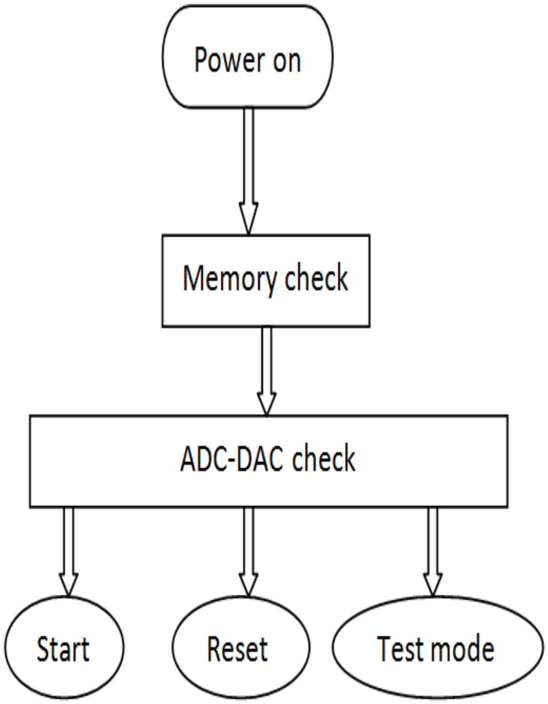


5. PROGRAMMING THE MICROCNTROLLER:

Microcontroller must be programmed to follow the sequence of steps required to calculate the characteristic impedance value of the cable. A source code can be attached to Microcontroller. is used to 'C' language is used to write the main program.

5.1 PROGRAM FLOWCHART:

When the meter is connected to the mains, the circuit components should be checked if they are working properly. Checking the Microcontroller memory is necessary every time it is turned on. So a routine is included in the program to assign some value to each memory location and retrieve it to compare. On mismatch of the values, error message saying "memory not working" is displayed. All memory locations are initiated to zero to avoid random values. ADC-DAC working is also checked. By controlling the switch, ADC and DAC are connected. A digital value is given to DAC and the same is compared to digital output of the ADC. On mismatch, an error message is displayed on the LCD. If everything goes fine with the checking, the Microcontroller will proceed to calculate the characteristic impedance value. Below is the flowchart depicting the same:



'START' mode:

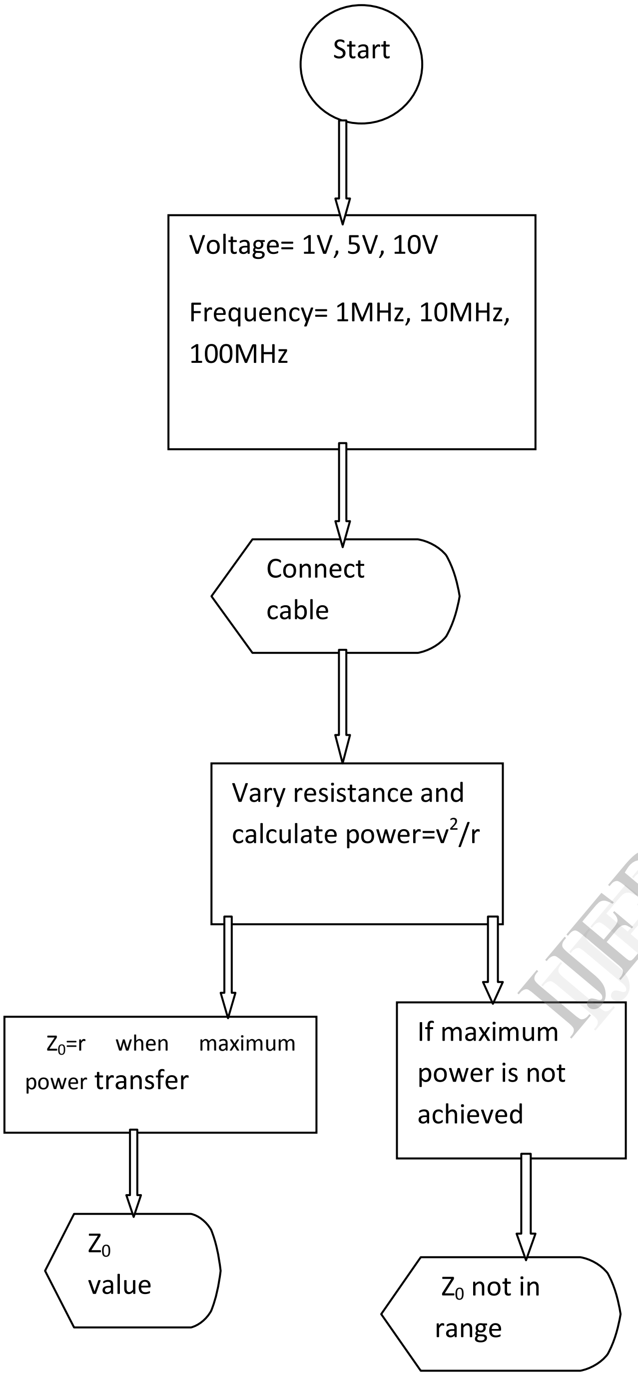
By pressing the start button and connecting the cable to the terminals provided, characteristic impedance value can be calculated. The voltage amplitude and frequency can be selected by changing the knob positions. The internal circuit changes accordingly (R1 value in the op amp square wave generator circuit). A message "connect cable" is displayed on the LCD. After the cable is connected, output of the DAC is used to vary the MOSFET resistance value(R). Voltage from ADC output is used to calculate the power delivered (V^2/R). this is continued until maximum power is delivered and the corresponding value is displayed as Z_0. The same is shown in the following flowchart:

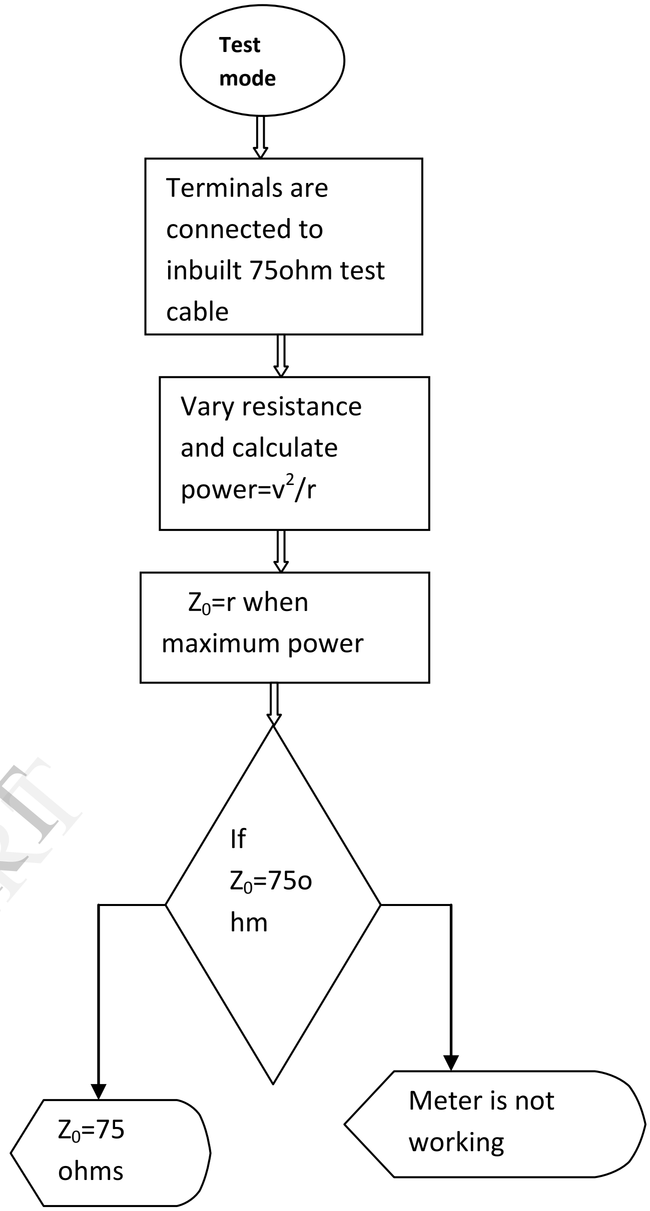
'TEST' mode:

In the test mode, the inbuilt sample cable is connected instead of the external cable, using the switch. One of digital output of Microcontroller can control the switch. Thereafter the same operations are performed as discussed for START function.

RESET' mode:

On pressing RESET, the program counter goes to the starting memory location. The calculation can be restarted by using this option. This is given high priority in the program, so on pressing reset microcontroller aborts the present operation and starts the process from the beginning.

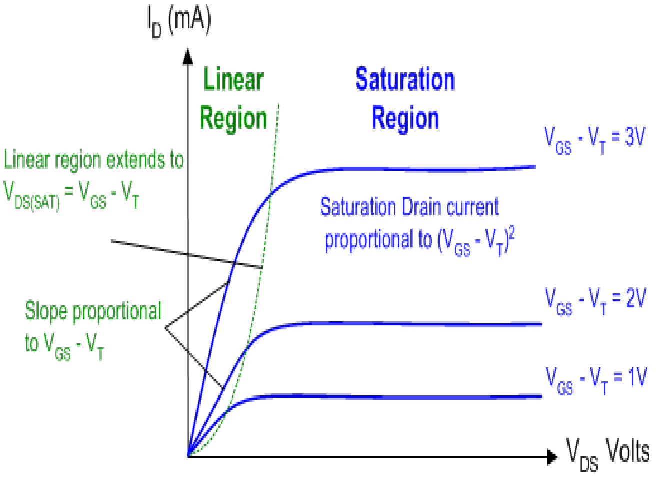




VOLTAGE CONTROLLED VARIABLE RESISTOR: MOSFET is used as the variable resistance in the circuit. By applying a transverse electric field across an insulator (generally SiO_2) deposited on the semiconducting material, the thickness and hence resistance of a conducting channel of a semiconductor material can be controlled. In enhancement MOSFET, application of electric field causes an increase in majority carrier density in the conducting regions.

A thin layer of a metal (aluminium) coated on the insulator acts as gate. By applying positive voltage to gate and grounding substrate, results in as electric field between drain and source. An inversion layer is formed by the minority charge carriers present in the substrate. As the positive voltage on the gate increases, the induced layer in the semiconductor increases and current flows from drain to source through it. Thus the conduction through the MOSFET is controlled by the gate voltage.

For proper functioning, the gate to source voltage (V_{GS}) and drain current are suitably selected by biasing the MOSFET.
In the region before pinch off , where V_{DS} is small, the drain to source resistance R_D can be controlled by the bias voltage $V_{GS.}$



Equations:

$$I_D = 2k\left((V_{GS} - V_T)V_{DS} - \frac{V^2{}_{DS}}{2}\right) \textit{ for linear region}$$

$$I_D = k(V_{GS} - V_T)^2 \textit{ for saturation region}$$

The resistance (R_D) varies with voltage (V_{GS}) according to the above equation, acting as a voltage controlled resistor. By using the above circuit in the meter, the resistance is varied until maximum power is transmitted and corresponding value is displayed as characteristic impedance of the cable. The code to run the system is given in the **annexure 2.**

5. SUMMARY:

An attempt is made to automize the measurement of characteristic impedance in nuclear instrumentation of fast reactors. A prototype will be made and qualified.

Ref:1. Wikipedia

Annexure 1

CHARACTERISTIC IMPEDANCE OF A CABLE:

Transmission line:

A transmission line is a specialized cable designed to carry alternating signals of radio frequency. These signals are of high frequency and their wave nature should be considered. Different cables are used as transmission lines depending on frequency and nature of the signal. Types of transmission line include coaxial cable, ladder line, wave guides, twisted pair etc. Wave guides are physical structures that guide electromagnetic waves in the optical spectrum. Common type wave guides include optical fiber, dielectric slabs which use the principle of total internal reflection. Twin lead cables have copper wire at a distance. These are used for parallel transmission. Commercially manufactured twin lead is ladder line, used in balanced connection of antennas. Coaxial cable is considered as the main form of transmission line.

Coaxial cable: It is an electrical cable with an inner conductor surrounded by a flexible, tubular insulating layer, surrounded by tubular conducting shield. These are mainly used as feedlines connecting radio transmitters and receivers with their antennas, in computer network and distributing cable television signals. All these applications involve high frequency signal transmission, where small amount of reflections could distort the signal and may fail to serve its purpose.

Applicability of transmission line theory:

In many electric circuits, the length of the wires connecting the components can be ignored. That is, the voltage on the wire at a given time can be assumed to be the same at all points. However, when the voltage changes in a time interval comparable to the time it takes for the signal to travel down the wire, the length becomes important and the wire must be treated as a transmission line. Stated another way, the length of the wire is important when the signal includes frequency components with corresponding wavelengths comparable to or less than the length of the wire.

The cable or wire is treated as a transmission line if the length is usually greater than 1/10 of the wavelength. At this length the phase delay and the interference of any reflections on the line become important and can lead to unpredictable behavior in systems which have not been carefully designed using transmission line theory.

Definition:

Characteristic impedance (Z_0) of a uniform transmission line is the ratio of the amplitudes of a single pair of voltage and current waves propagating along the line in the absence of reflections.

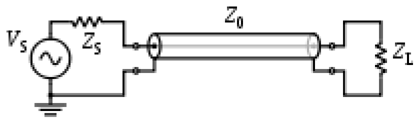
SI unit of characteristic impedance is the ohm.

The voltage and current phasors on the line are related by the characteristic impedance as:

Z_0 =V/I

The characteristic impedance of a lossless transmission line is purely real, that is, there is no imaginary component ($Z_0 = |Z_0| + j0$). Characteristic impedance appears like a resistance in this case, such that power generated by a source on one end of an infinitely long lossless transmission line is transmitted through the line but is not dissipated in the line itself.

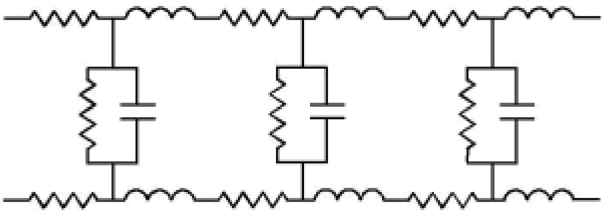
A transmission line of finite length that is terminated at one end with a resistor equal to the characteristic impedance ($Z_L = Z_0$) appears to the source like an infinitely long transmission line. In this case Z_0 corresponds to the input impedance.



$Z_L = Z_0$

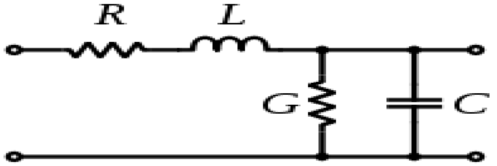
2.3.1 Transmission line model:

Every transmission line consists of circuit elements distributed along its length. Because current flows through the conductors, the line has series inductance, and because there is always a return path, which is normally another adjacent conductor, it has parallel capacitance. The series inductance and parallel capacitance are the dominant elements in the equivalent circuit of lines, and are present even in theoretically perfect cases. But in real lines the conductors are not perfect, so they also have some series resistance, and the dielectric or insulation separating the two conductors is not perfect so it has some parallel resistance. The series and parallel resistance are less significant than the inductance and capacitance, unless there is a fault in the line.



The transmission line model represents the transmission line as an infinite series of two-port elementary components, each representing an infinitesimally short segment of the transmission line:

a) The distributed resistance *R* of the conductors is represented by a series resistor (expressed in ohms per unit length).
b) The distributed inductance *L* (due to the magnetic field around the wires, self-inductance, etc.) is represented by a series inductor (Henries per unit length).
c) The capacitance *C* between the two conductors is represented by a shunt capacitor C (farads per unit length).
d) The conductance *G* of the dielectric material separating the two conductors is represented by a shunt resistor between the signal wire and the return wire (Siemens per unit length).



In the real line the elements are distributed continuously along the line, and are not lumped at intervals along the length as shown.

In the above figure, each section of the equivalent circuit looks like a low pass filter, so the effect of the inductance and capacitance is to limit the bandwidth of the signals which the line can transport, with higher frequencies being attenuated more than lower ones. The series and parallel resistances result in losses down the line, reducing the ability of the line to transport the signal power efficiently

The characteristic impedance is given by

$$\mathbf{Z_0}=\sqrt{\frac{R+2j\omega L}{G+2j\omega C}}$$

Where R, L, G, C are the corresponding values per unit length and ω is angular frequency.

FOUR TERMINAL MODEL:

For the purposes of analysis, transmission line can be modeled as a two-port network (also called a quadrupled network), as follows:

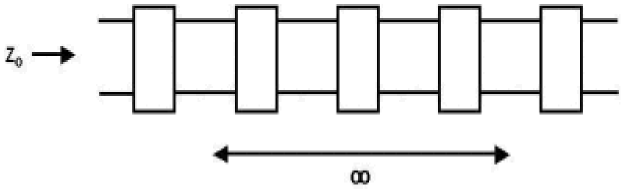
In the simplest case, the network is assumed to be linear (i.e. the complex voltage across either port is proportional to the complex current flowing into it when there are no reflections), and the two ports are assumed to be interchangeable. If the transmission line is uniform along its length, then its behaviour is largely described by the single parameter characteristic impedance. Typical values of Z_0 are 50 or 75 ohms for a coaxial cable, about 100 ohms for a twisted pair of wires, and about 300 ohms for a common type of untwisted pair used in radio transmission.

When sending power down a transmission line, it is usually desirable that as much power as possible will be absorbed by the load and as little as possible will be reflected back to the source. This can be ensured by making the load impedance equal to Z_0, in which case the transmission line is said to be matched.

INFINITE LENGTH CABLE:

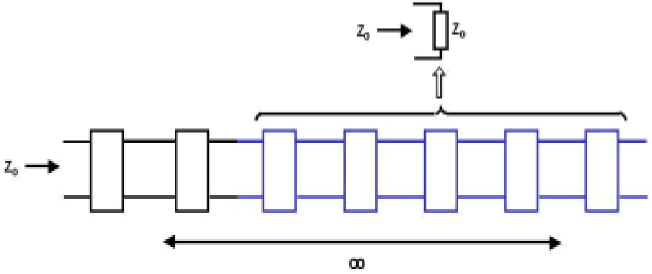
Definition - The characteristic impedance, Z_0, of a line is the input impedance of an infinite length of the line.

The transmission line model of a cable can be simplified to an equivalent circuit by using boxes to represent each section, as shown below. The input impedance looking into the one end of this infinite line can be taken as characteristic impedance since the reflections are zero.

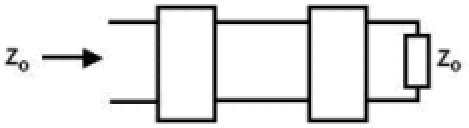


As the line is infinitely long, more sections can be added as shown below, without making any difference to its properties.

Since the length is still infinite, the input impedance is still the characteristic impedance.



The original line could be replaced by single impedance, Z_0, as shown below, and the input impedance would be unchanged.



Therefore, if a finite length of line is terminated in its characteristic impedance, Z_0, then its input impedance will also equal Z_0 and it acts as infinite length line without any reflections.

Annexure 2:

PROGRAM CODE:

-
  ```
  void DAC_Init(){ //
  to connect to dac
  TRISD=0; //to declare portD as output
  port
  TRISC3_bit=0;
  TRISC4_bit=0;
  TRISC5_bit=0;
  TRISC6_bit=0; //four more output pins
  required for dac(12 bit)
  TRISB4_bit=0; //to WR pin of
  dac(declared as outputpin)
  TRISB5_bit=0; //to CLR pin of
  dac(declared as output)
  TRISB6_bit=0; //to latch the dac(declared
  as output)
  PORTD=0; //to give a value of zero
  initially(lower 8 bits)
  PORTC=0; //to give a value of zero
  initially(upper 4 bits)
  RB4_bit=1; //set WR pin
  RB5_bit=1; // clear this bit to clear the
  dac
  RB6_bit=1; //clear this bit to latch the
  value
  }
  ```

-
  ```
  void memory_check() {
  char temp=0,temp1=0; // variables declared to assign
  values and to retrieve values
  FSR0=0;

   do{
      INDF0=FSR0;//assign the address value to the
  register
      temp= INDF0; //retrieve the value from the
  memory
      if(temp!=FSR0){     //compare the value to check
        Lcd_Init();    //to initialise lcd (connect the pins)
        Lcd_Out_Cp(" memory incorrect"); //display the
  memory is not working using built in lcd function
         break;      //**command to halt the uc or go to
  off mode
        }
      Else
        FSR0++;
     } while(FSR0<=0xFF);
  temp=0;
  for(FSR0=0xFF;FSR0<=0xFFF;FSR0++,temp++){//
  after FSR0=0xFF, FSR0 cannot be assigned to the
  memory register
     INDF0=temp;
     temp1=INDF0;
     if(temp1!=temp){
       Lcd_Init(); //to initialise lcd
       Lcd_Out_Cp(" memory incorrect"); //display the
  memory is not working
       break;     //**command to halt the uc or go to
  off mode
       }
     }
  for(FSR0=0x00;FSR0<=0x3FF;FSR0++){
    INDF0=0;//to initiate all the memory locations to
  zero
    }
  }
  ```

-
  ```
  void dac_adc_check(){
  ADC_init();
  DAC_init();
  RA2_bit=1;
  PORTD=0x088;
  if(ADRES!=0x88){
   Lcd_Init();
   Lcd_Out_Cp(" adc or dac not working");
   //**command to exit from the program
   }
  }
  ```

```
int voltage;
```

-
  ```
  int voltage_from_lookup_table(int resistance){
  //luk up using table in memory
  TBLPTR= 0x266+resistance;     // say 0x266 has
  voltage value for zero resistance, where the table
  starts
  //**command to read frm memory TBLRD*;
  //**read into TABLAT and increment
  voltage= TABLAT ; //get data
  ```

```
return voltage;
}
```

-
  ```
  int resistance_for_known_voltage(int voltage){
  // function to get resistance for voltage transmitted,
  for Zoc and Zsc
   int *ptr;
   int temp=0;
   int resistance;
   do{
    temp++;
    ptr=0x266+temp;
    }while(voltage<=(*ptr)&& temp<=1000);
   if(temp>=1000){ //to check if Z is
  in the range of 10ohm to 1000ohm
     Lcd_Out_Cp(" ci is not in range"); //to
  declare Zoc or Zsc are not in the range
     //**command to exit //** to halt the program
  at this point
     }
   resistance=*ptr;
   return resistance; // return the value to assign it to
  Zoc or Zsc
   }
  ```

-
  ```
  ADC_Init(); // Initialize ADC
  module with default settings
  ```

-
  ```
  unsigned ADC_Get_Sample(unsigned short channel);
  //default function of adc to get analog value from the
  specified channel
  ```

-
  ```
  unsigned ADC_Read(unsigned short channel);
  //default functions in the library to get the digital
  value into a variable
  ```

-
  ```
  int adc_output_peak_voltage(){ //to get the
  peak voltage value to be used in power calculation
  int output_adc[30];
  int vnum=1;
  int temp;
  output_adc[0]=0;
  do{
  output_adc[vnum]=ADC_Get_Sample(7);
  temp=vnum-1;
  if(output_adc[vnum]<output_adc[temp])
   output_adc[vnum]=output_adc[temp];
   }while(vnum<=30);
   return output_adc[30];
  }
  ```

-
  ```
  void latch_init(){
  RE0_bit=0; //to enable output of
  the latch
  RE1_bit= 1; //to select the latch
  }
  ```

```
int voltage_frm_lukup_table(int resistance){ // luk up
using pointers
int *ptr; //declare a pointer
ptr=0x266+resistance; //get the adress of the voltage
required at ptr assuming tabular values start at 0x266
voltage=*ptr; //store the value at voltage variable
return voltage;
}
```

-
  ```
  void dac_output_voltage(int resis)(){
  int voltag;
  voltag= voltage_frm_lukup_table(resis);
  PORTD=voltag;
  RC3_bit=voltag>>8;
  RC4_bit=voltag>>9;
  RC5_bit=voltag>>10;
  RC6_bit=voltag>>11;
  }
  ```

```
//pins assigned to control switches
// Lcd pinout settings
sbit LCD_RS at RA4_bit;
sbit LCD_EN at RA3_bit;
sbit LCD_D7 at RD7_bit;
sbit LCD_D6 at RD6_bit;
sbit LCD_D5 at RD5_bit;
sbit LCD_D4 at RD4_bit;
sbit LCD_D3 at RD3_bit;
sbit LCD_D2 at RD2_bit;
sbit LCD_D1 at RD1_bit;
sbit LCD_D0 at RD0_bit;
sbit LCD_RS_Direction at TRISA4_bit;
sbit LCD_EN_Direction at TRISA3_bit;
sbit LCD_D7_Direction at TRISD7_bit;
sbit LCD_D6_Direction at TRISD6_bit;
sbit LCD_D5_Direction at TRISD5_bit;
sbit LCD_D4_Direction at TRISD4_bit;
sbit LCD_D3_Direction at TRISD3_bit;
sbit LCD_D2_Direction at TRISD2_bit;
sbit LCD_D1_Direction at TRISD1_bit;
sbit LCD_D0_Direction at TRISD0_bit;

 int Zi;
 int Z0;
 int v;
 int temp1,temp2;
 unsigned int vcr,m;
double power[100];
```

-
  ```
  void main() {
  Lcd_Init();
  Lcd_Out_Cp("connect the cable"); //
  start of the program
  RE0_bit=0; //to latch the lcd
  DAC_Init();
  Zi=10;
  do{
   dac_output_voltage(Zi);
   v =adc_output_peak_voltage() ;
   power[m]=(v*v)/Zi;
   Zi++;
   }while((power[Zi-2]>power[Zi-1])|| (power[Zi-
  1]>power[Zi-3]));
  RB6_bit=0; //to latch dac
  Z0=Zi-3+10; //Zi-3+10 is the value of the
  impedance where maximum power transmissin
  occurs, +10 for series resistance
  Lcd_Init();
  ```

```
  Lcd_Out(1,1,&Zi);        // display characteristic
  impedance
  }
• void test_mode(){
   RA0_bit=1;
   Lcd_Init();
  Lcd_Out_Cp("test mode");        // start of the
  program
  RE0_bit=0;        //to latch the lcd
  DAC_Init();
  Zi=10;
  do{
    dac_output_voltage(Zi);
    v =adc_output_peak_voltage() ;
    power[m]=(v*v)/Zi;
    Zi++;

•
•

 *
```

```
   }while((power[Zi-2]>power[Zi-1])|| (power[Zi-
  1]>power[Zi-3]));
  RB6_bit=0;        //to latch dac
  Z0=Zi-3+10;        //Zi-3+10 is the value of the
  impedance where maximum power transmissin
  occurs, +10 for series resistance
  Lcd_Init();
  if(Z0==75)
  Lcd_Out_Cp("working normal, no error");
  Else
  Lcd_Out_Cp("error, test result not equal to 75");
  }
• void reset_mode(){
  Lcd_Cmd(_LCD_CLEAR);        // Clear Lcd
  display
  main();
```