Transmission lines and electromagnetic waves
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Lecture - 13
Demonstration of Impedance Matching Using VNA

All right. I think we will get started. It is just a small demo about things that you have already studied, right.

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So, this is a transmission line, all right. In specific, it is a kind of a transmission line, all right. So, this particular one is a coaxial cable, all right and there are many many kinds of coaxial cable that you can find in the market, this is just one version of them, right.

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So, it has you know a connector at the centre and a connector around it, I mean a conductor in the centre and the conductor around it. So, it is a straight conductor on the centre and then a braided conductor around it, and the ends are having some kind of a connector. These are SMA connectors, sub miniaturized version A SMA connectors that can go into some devices, which can probe RF, ok.

So, here we are having a specific cable, all right, so I believe this is RG-136 ok. So, it is a radio guide one There are a number of coaxial cables that you can buy depending on the application. This particular one goes you know up to some 500 MHz to maybe 600, 700 MHz with reasonable losses, ok. So, this is a typical transmission line, ok. There are also other things that we have.

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So, I have a different cable over here. So, an RG-58 cable. So, this is a 50 Ω characteristic impedance cable. This is also a 50 Ω characteristic impedance cable. They come in different lengths, all right different colours, different compositions. For example, the centre could be made up of copper, it could be made up of copper coated steel, or it could be braided with aluminium on the top. The jacket material could be different in different companies. So, it just depends, all right.

So, these are also very rigid. You cannot bend them you know with very short radii, there are guidelines for how much you can bend them and how much you cannot bend them and all that, ok. So, these are some short stubs of cables that I thought I will come and show you. But most of you may have set the top box in your house. You must have seen a coaxial cable in your houses that particular one is known as an RG-6 cable, ok radio guide 6. And the good thing about that cable is it is fat, so it is less lossy, all right and it goes up to 3 GHz, ok, up to 3 GHz. So, that is the much better cable than what we have here. These are short stubs, all right.

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So, what I will do is there are more patch cards over here, all right. This particular connector is known as an SMA connector, all right and this is what you will commonly notice in microwave labs extra, ok. Now, what I will do is I will show you some specifications of these cables first, then I will show you where these cables are connected. All right and then I will show you the specification of the machine to which it is connected, all right. How to read a data sheet and all that and then we will see how it solidifies what we have learnt in the class, ok.

So, I will first start with cables, ok. I am opening for some common cables RG-58 is a very common cable that you know I learnt to use may be when I was beginning to read this, ok.

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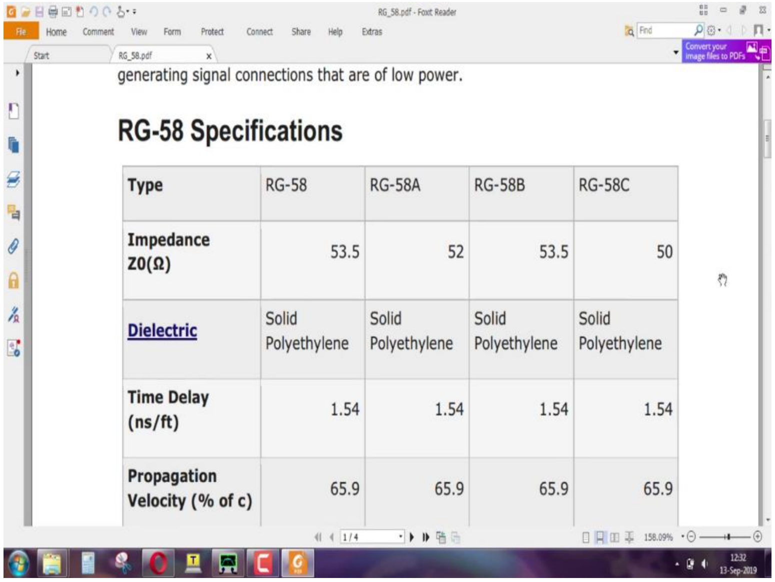
generating signal connections that are of low power.

RG-58 Specifications

Type	RG-58	RG-58A	RG-58B	RG-58C
Impedance Z0(Ω)	53.5	52	53.5	50
Dielectric	Solid Polyethylene	Solid Polyethylene	Solid Polyethylene	Solid Polyethylene
Time Delay (ns/ft)	1.54	1.54	1.54	1.54
Propagation Velocity (% of c)	65.9	65.9	65.9	65.9

So, let us have a look at your typical specifications. So, if you look over here impedance z naught this is the characteristic impedance of the cable, all right. So, there are different varieties RG-58, 58 A, 58 B, 58 C extra. So, all of them have a nominal impedance of about 50 *Ω*s. So, 53.5, 52, 53.5, *Ω*s extra. These are some nominal impedances. So, the dielectric material in all of them is solid polyethylene is what is given, all right.

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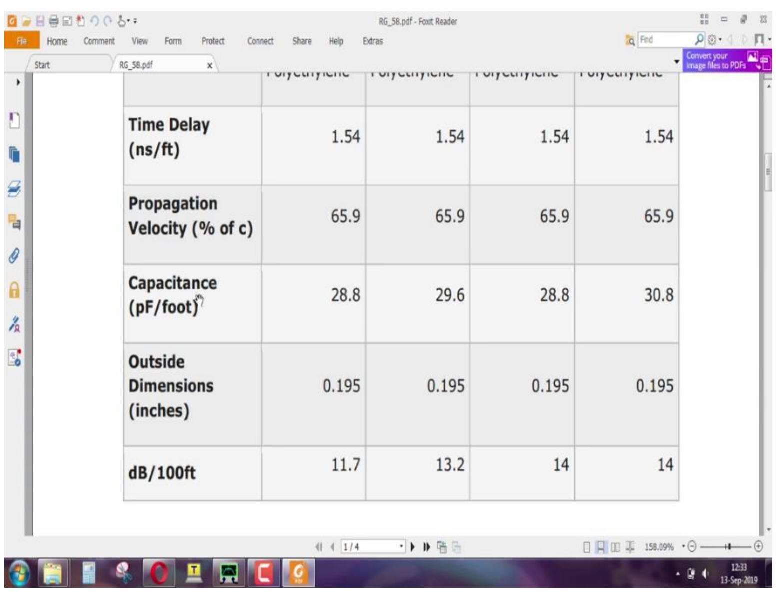
Time Delay (ns/ft)	1.54	1.54	1.54	1.54
Propagation Velocity (% of c)	65.9	65.9	65.9	65.9
Capacitance (pF/foot)	28.8	29.6	28.8	30.8
Outside Dimensions (inches)	0.195	0.195	0.195	0.195
dB/100ft	11.7	13.2	14	14

So, this is the material between the centre and the outer braided. I will show you how the structure looks. I cannot cut this cable, but I will show you a picture of what it would look like.

Time delay $ns/feet$ using some combination of SI and imperial units, does not matter. If the manufacturer is from a you know English countries then you will have $ns/feet$, all right. So, also in the US it is pretty common to use feet extra, but it does not matter, all right.

So, time delay is 1.5 $ns/feet$ and then they give you something known as propagation velocity below that percentage of C. Here, it says there it's almost 66 percent, ok. So, typical cables have velocities of up to $2 * 10^8\ m/s$. This is the velocity, ok. So, the first class we said that no signal will travel at infinite velocities. The upper limit is the speed of light $3 * 10^8\ m/s$ and in most of these cables which operate let say GHz frequencies the propagation velocity is 66 percent the speed of light seems to be very common, right maybe you can pick a varieties of cables, 66 percent the speed of light is about $2 * 10^8\ m/s$, ok.

Now, there are also other things, which will solidify what we have seen in the class. For example, capacitance is measured in $pf/foot$. We said that it is a distributed parameter in the first few lectures, all right. It is given as 28.8 $pf/foot$, I think it should be clear to you that this is how the specifications are given. So, distributed parameters. So, the longer you buy more the capacitance you will be adding per foot, right.

So, some outside dimensions and we also did you know dB calculations for input, output powers, relative power extra. So, it tells you how much of a loss we are going to be having in your transmission line. Here it says that it is about 11.7 dB per foot, but we have to take all these things with a pinch of loss. This may be the best loss or this may be the worst loss. It cannot be the worst loss because it's only 11 dB, so maybe it is somewhere in between, ok. We will see more details later, ok.

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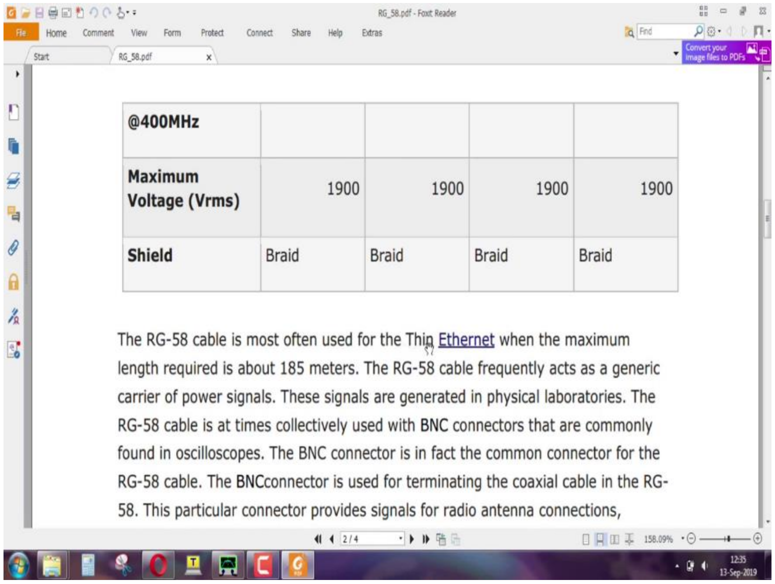

@400MHz				
Maximum Voltage (Vrms)	1900	1900	1900	1900
Shield	Braid	Braid	Braid	Braid

The RG-58 cable is most often used for the Thin Ethernet when the maximum length required is about 185 meters. The RG-58 cable frequently acts as a generic carrier of power signals. These signals are generated in physical laboratories. The RG-58 cable is at times collectively used with BNC connectors that are commonly found in oscilloscopes. The BNC connector is in fact the common connector for the RG-58 cable. The BNCconnector is used for terminating the coaxial cable in the RG-58. This particular connector provides signals for radio antenna connections,

And it says maximum, ok. So, it is tells the dB per foot it has 400 MHz, ok. At 400 MHz about 11.7 dB decibels per foot. You can always go back and use our formula and try to calculate 10 log to the base 10 output power by input power is equal to minus 11 dB. How much is the ratio of V out to V in? You can make a calculation, all right from the notes.

Maximum voltage that you can apply is absurdly high 1900 volts, ok. And the shield that is the outer conductor that you are having, all right and also to provide it insulation from external electric fields. So, this outed braider conductor is a I mean it is a braided conductor it is not a you know film or something like that. That is what that is the detail that is given. And then there is some tit bits of information.

If you see here the RG-58 cable is most often used for thin internet, all right. When the maximum length is about 185 meters, now this is a piece of information that you may not have been aware of, ok. So, its use for thin internet, ok, when you know the maximum length required is about 185 meters of course, right. Nowadays, we have Wi-Fi, cell phones and all that, but you know if you want to have a wired internet connection, this could have been a not this particular RG-58 would have been a candidate, this is a different one. The thing is 319 something, all right.

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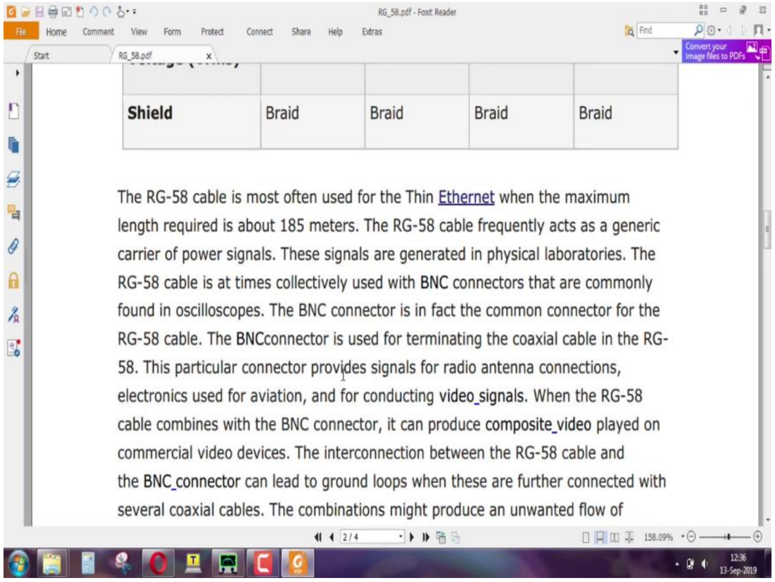

So, you could also have different connectors at the end. You could have a BNC connector, for low frequencies you could have different types of connectors depending upon your application, ok.

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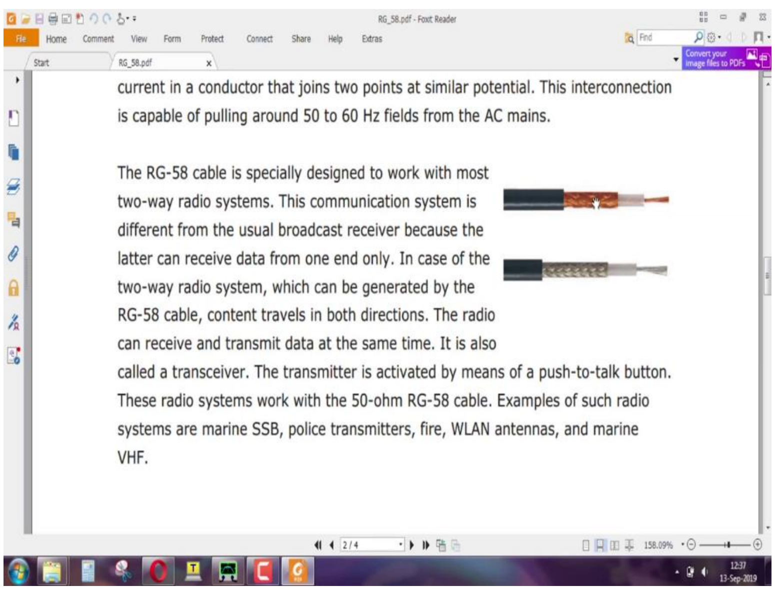

So, this is how the cross section looks because I could not cut these wires. I just wanted to show you that there is an outer part, all right. And then there is a braided conductor inside and there are different cables we saw RG-58 A, B extra.

Some of the specifications could be slightly different because of the materials and the way they are being used. For example, I can see clearly that the outer braided part is copper in the first one, all right and its aluminium or maybe steel I do not know, all right looks like aluminium. And then there is a dielectric, which is poly ethylene in this case, and then there is a core which is again copper. This is what is the structure. So, the central part of the wire is connected to the pin over here, which is going to carry a signal, and the outer one is going to behave like a ground, ok. So, these connectors are just pressed and crimped that is it, ok.

So, the outer part has to make contact with the outer copper thing that is a present over here and the centre part has to make contact with the centre male part over here that is all, ok. So, again this is a 50 Ω connector, I mean 50 Ω cable, right. So, there are many many more things that one can read, right.

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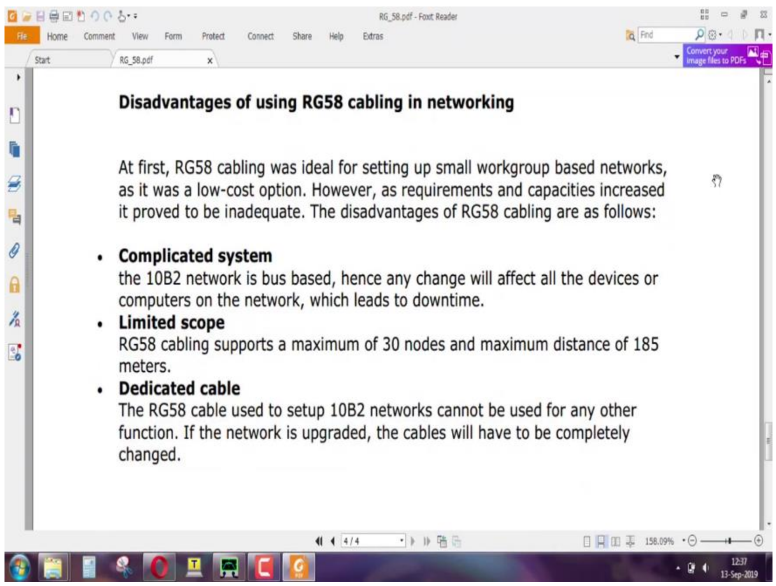

So, I wanted to just put this also. This is a very good document because it also gives you some limitations about what can be done, what cannot be done. RG-58 cabling supports up to 30 nodes maximum distance of 185 meters, ok. So, I think this is very interesting. Let us look at some more things related to the cables.

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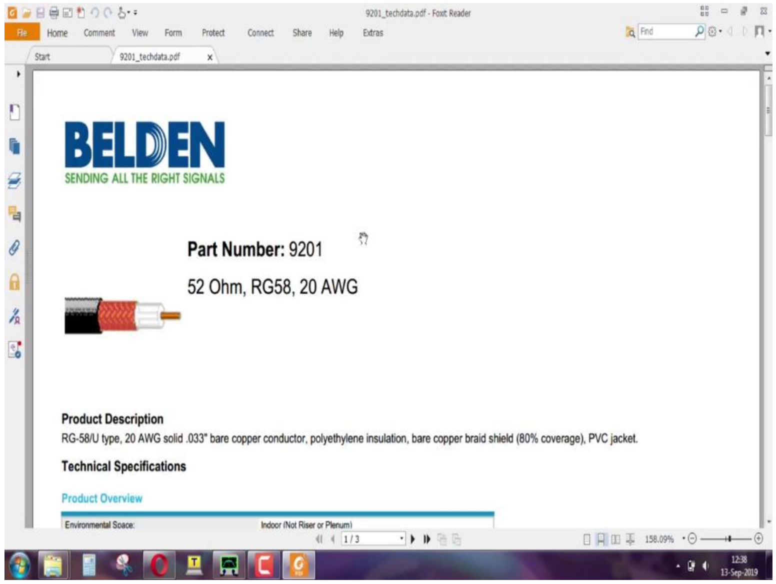

So, this is another company which makes cables RG-58 according to the standards, ok. So, it is 52 Ωs nominal characteristic impedance, all right. So, it also tells you what is the gauge of the solid code that they are using, what is the diameter of the copper conductor in between I mean in the centre, ok. So, it is saying that its 0.033 inches, 20 AWG is the gauge of the solid core that is present over there. Polyethylene installation, now we can understand that there are many commonalities across manufacturers because they are conforming to some kind of a standard, right. So, bare copper braid shield, then they say there is a PVC jacket on the outside to protect that, right. This is the composition, right.

And I will just go to some technical specifications.

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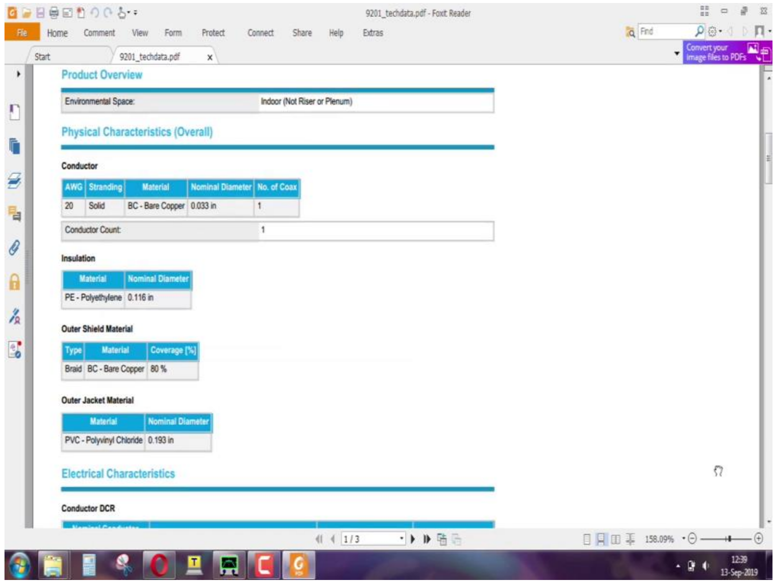

So, again solid core polyethylene dielectric between the two conductors, ok. Braided outer shield, right.

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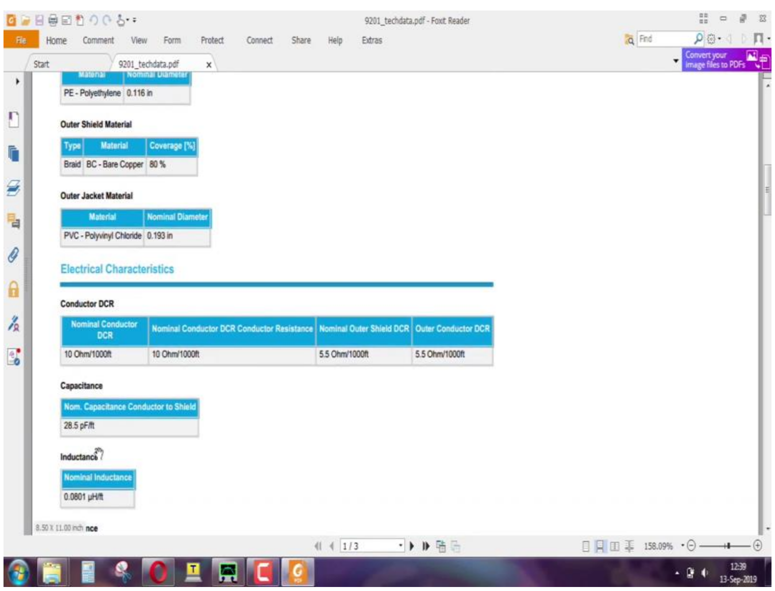

PVC outer jacket material and then let us see something nominal conductor DCR, right. So, this is $10 \frac{\Omega}{1000\ feet}$. Again, you notice that everything is coming in distributed units, ok. $10 \frac{\Omega}{1000\ feet}$ this is the typical you know resistance per unit length that you will be having in these cables, right. 10

$\frac{\Omega}{1000\ feet}$ or for the outer shield you know is 5.5 $\frac{\Omega}{1000\ feet}$, right. So, it is a very tiny amount of resistance depending upon the application. You cannot use it for very very long as you know connections anyway.

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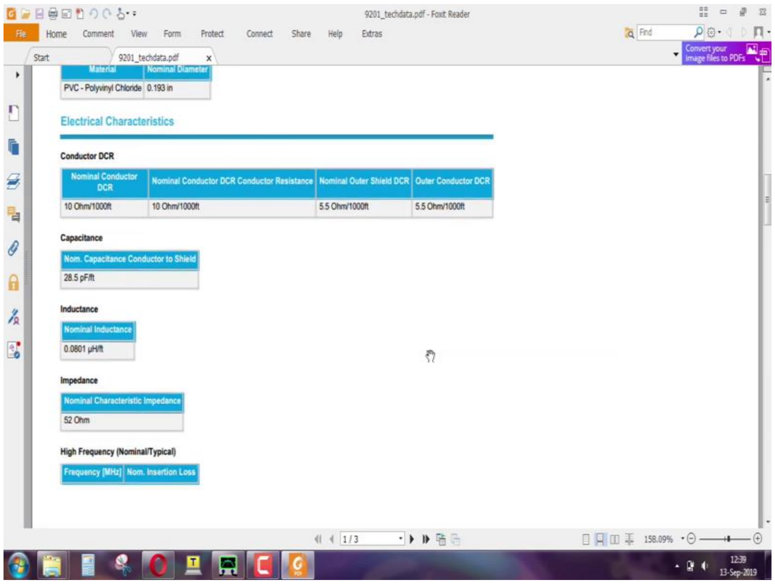

So, again capacitance, nominal capacitance conductor to shield that is conductor to shield, measured across the two conductors with a dielectric in between is again distributed parameter which is 28.5 $pf/feet$. So, everything is in distributed parameters and nominal inductance is 0.08 $\mu H/feet$. So, these are roughly the range of values you can expect, some 100 pf capacitance per you know feet per foot, all right and you know orders of $\mu H/feet$, all right. This at least that much you should be knowing you cannot absolutely, right, henry, farad extra. So, these are very tiny values of capacitances and tiny values of inductances.

This is just for you to get a feeling for the numbers in actual cables. Nominal characteristic impedance is 52 Ωs.

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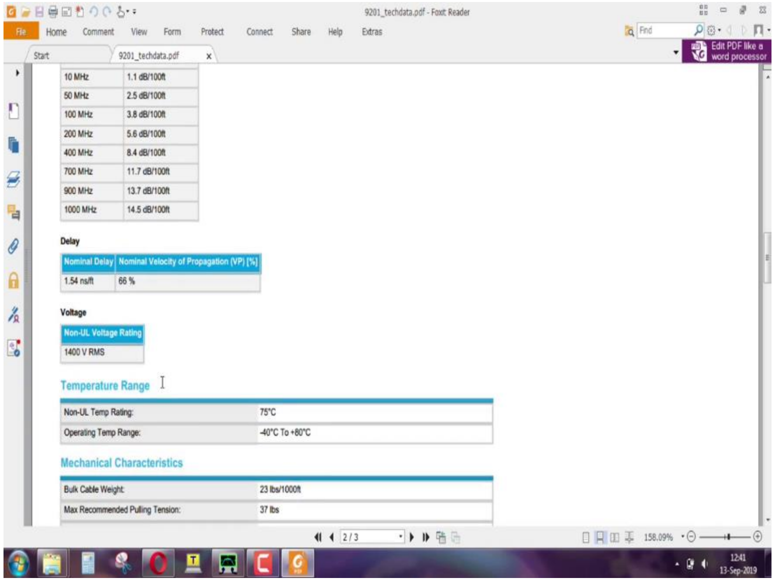

And then high frequency insertion loss that is output power to input power, right taken in a dB. Also you see how it has been given. At 1 MHz MHz it is only 0.3 $\frac{dB}{100\ foot}$. Not sure, are you able to see, right it is only 0.3 $\frac{dB}{100\ foot}$ 10 MHz 1.1 $\frac{dB}{100\ foot}$ and then at 1 GHz GHz its 14.5 $\frac{dB}{100\ foot}$. So, the lesson here is as you start having higher frequencies going through these cables the losses will typically become higher, ok.

So, this also means that a transmission line which worked for low frequencies need not necessarily work for very high frequencies, ok. So, the general rule is as your frequency increases the loss increases that is the general rule that we are seeing over here, right. Again the delay is 1.5 $ns/foot$; that means, then it is about 66 percent of the speed of light that is $2 * 10^8\ m/s$. The voltage that you can give is about 1400 volts. So, similar to what we solve with the other manufacturers, 1900 volts extra.

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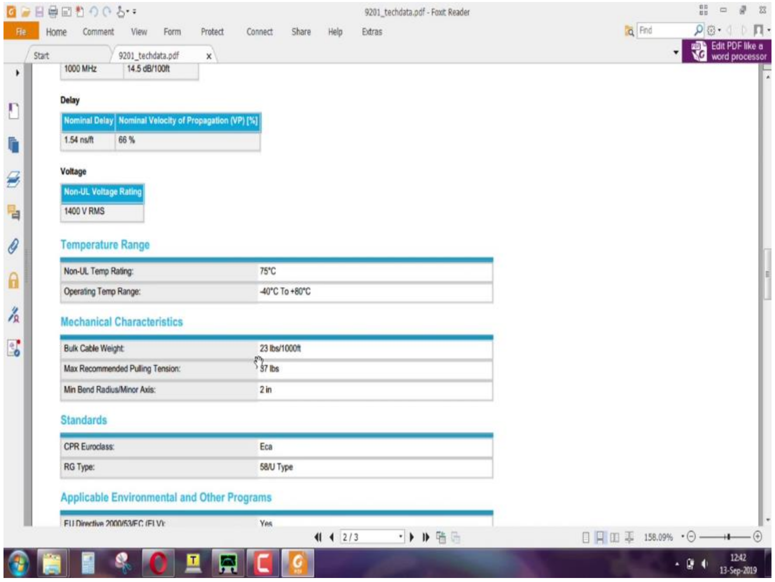

On top of that you know they give you an operating range between minus 40 and plus 80 degree centigrade and then on top of that there are some mechanical characteristics: how much you can pull, how much you can bend, all these things could be providers. So, these are typical data sheets of, you know, cables that are available in the market, ok.

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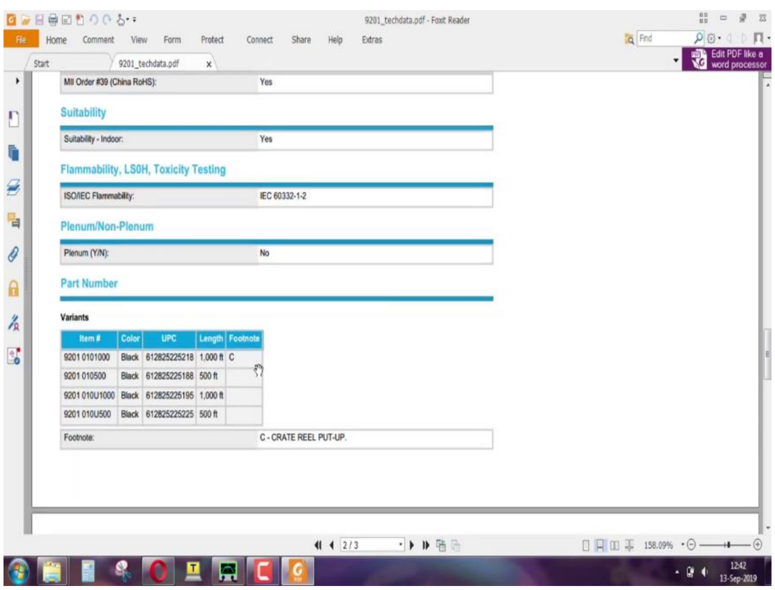

And there are some variants, right and different variants may have different colour jackets to just tell them that you know yellow colour is for this, blue colour is for this, black colour it could be like that, ok. So, I think by now you should be able to at least digest the fact that many of the transmission lines available in the market for high frequencies indeed indicate you know distributed parameters. Seems like a very common termination a impedance or a characteristic impedance is about 50 Ωs. The ones that you are using for your cable TV, RG-6 cables have characteristic impedance of 75 Ωs and not 50 Ωs, ok. So, it depends, but 50 and 75 Ωs are reasonably common, ok.

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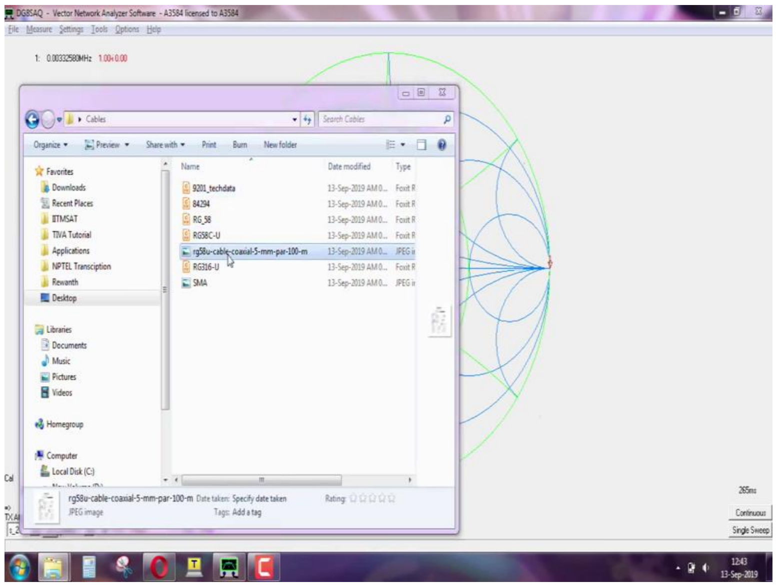

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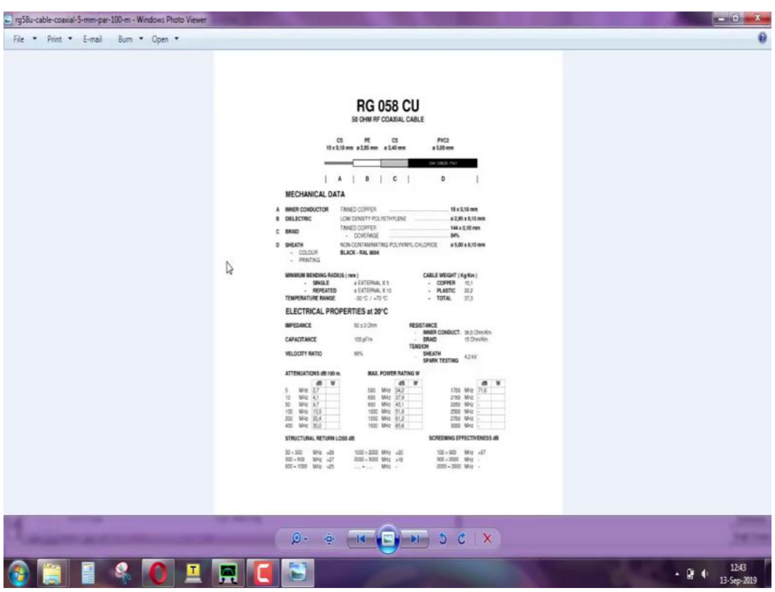

So, I think there are many more with respect to the cables. If you have time you can always Google. There are many companies which provide the same information in different ways.

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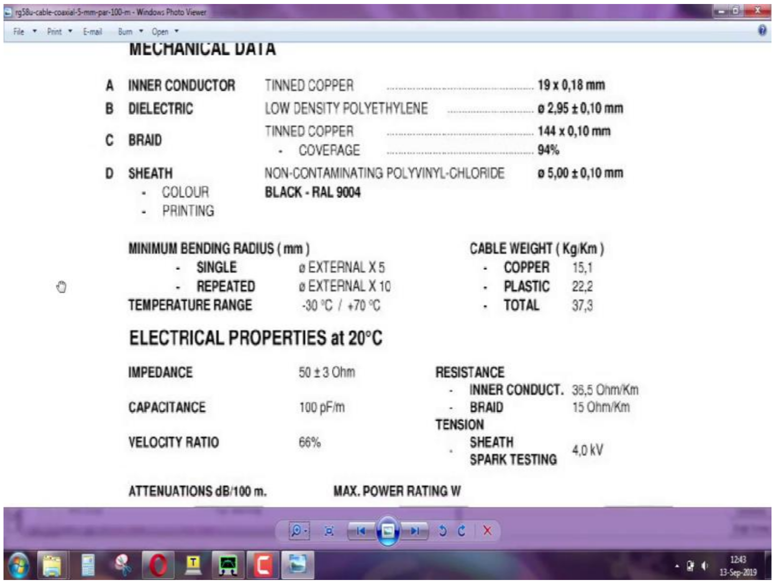
MECHANICAL DATA

A	INNER CONDUCTOR	TINNED COPPER		19 x 0,18 mm
B	DIELECTRIC	LOW DENSITY POLYETHYLENE		ø 2,95 ± 0,10 mm
C	BRAID	TINNED COPPER		144 x 0,10 mm
		- COVERAGE		94%
D	SHEATH	NON-CONTAMINATING POLYVINYL-CHLORIDE		ø 5,00 ± 0,10 mm
	- COLOUR	BLACK - RAL 9004		
	- PRINTING			

MINIMUM BENDING RADIUS (mm)		CABLE WEIGHT (Kg/Km)	
- SINGLE	ø EXTERNAL X 5	- COPPER	15,1
- REPEATED	ø EXTERNAL X 10	- PLASTIC	22,2
TEMPERATURE RANGE	-30 °C / +70 °C	- TOTAL	37,3

ELECTRICAL PROPERTIES at 20°C

IMPEDANCE	50 ± 3 Ohm	RESISTANCE	
		- INNER CONDUCT.	36,5 Ohm/Km
CAPACITANCE	100 pF/m	- BRAID	15 Ohm/Km
		TENSION	
VELOCITY RATIO	66%	- SHEATH SPARK TESTING	4,0 kV

ATTENUATIONS dB/100 m. MAX. POWER RATING W

In this case, in this case this is another manufacturer which is a giving you you know properties it says that characteristic impedance is 50 plus or minus 3 Ωs measured at 20 degrees centigrade. Capacitance of the order of 100 pf/m . I just pick this because it had units in SI a, So, resistance for the inner conductor is about 36.5 Ωs per kilometer, all right. So, velocity ratio 66 percent. At this stage you should at least know what numbers to expect from your a you know transmission line, ok. And things that are available to you when you are buying a transmission line or is this is this data, people give you the velocity factor, a people give you the impedance per unit I mean characteristic impedance and capacitance inductance per unit length extra, ok. So, I think this is the basics of a cable.

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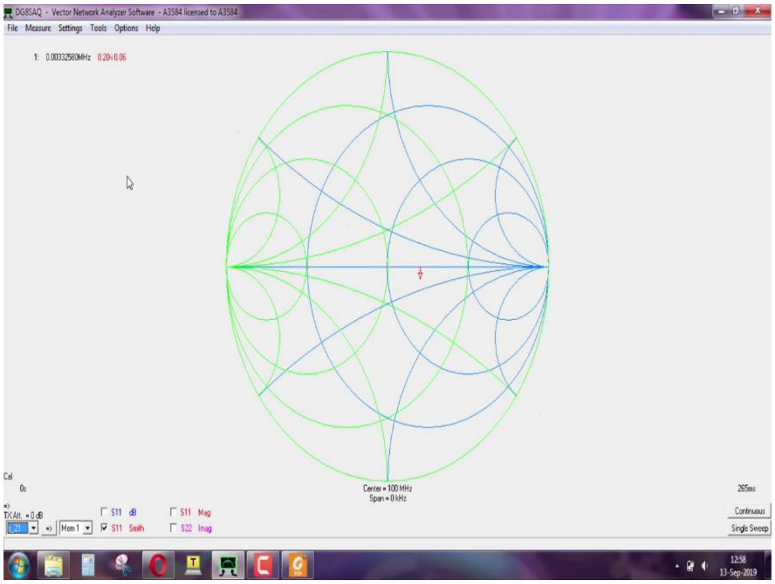

Now, what we are going to do is we are going to use these cables. I just picked this up from a lab, but the lab has very very sophisticated instruments, ok. And one of the instruments that the labs in IIT have is a vector network analyzer.

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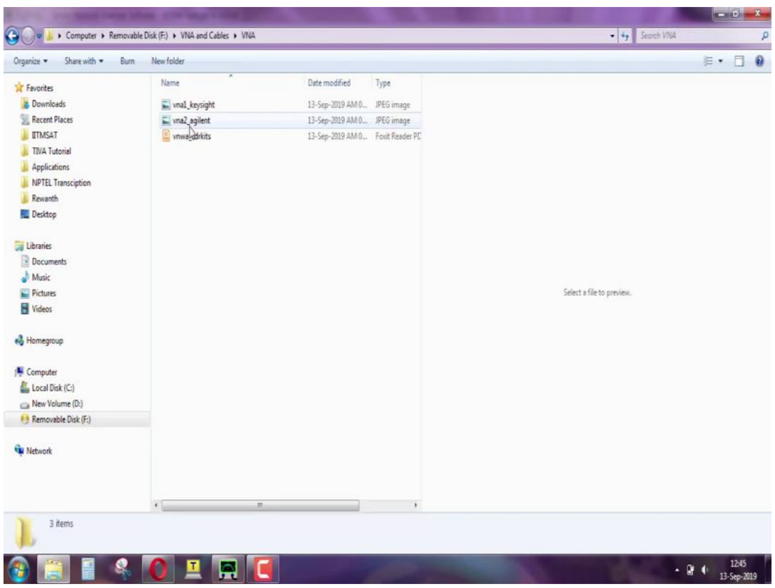

In short, they are known as VNA, ok vector network analyzer. These are the equipment that are made. So, I will open one of them as to how it looks.

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Some people may have seen this and thought that this looks like a giant oscilloscope that is close to what you know one can guess. So, I think in a RF lab in IIT, Madras they have a couple of this, right. So, this is from the key side and this is how it looks.

It is actually a giant machine, all right and it costs about 60 lakhs, 60 lakhs, all right. So, that is why I could not carry it here and show it because on the way if I dropped it that is it I have to repay for it for the rest of my life and my child would also have to pay. So, this is how it looks. It has some inputs. You can see that they have some specific connection types, ok. So, these could be depending on the frequencies or depending upon the availability extra. But there are also adapters to go from one type to another type extra. There are adapters which will allow you to do that.

So, if you see the screen there are some plots, typically they analyze in these cases s parameters, ok. So, we have not seen about s parameters and we are not going to see about s parameters in this course in an advanced course in waveguides and antennas you will be dealing exclusively with s parameters. They measure the s parameters specifically s 11 and s 21, ok. This is what is being shown here with respect to frequency.

On the right hand side is something that should be familiar to you, which is a Smith's chart, ok. So, you see that there is some display here with a Smith's chart. So, the hardware nowadays comes with this ability to plot impedances on a Smith chart. So, you would connect a cable to this then you would have a device, all right and then maybe you have some termination. So, you see on the Smith chart what is the impedance that is seen, all right. So, it can be used for a variety of purposes, but these are things with very very high capabilities, ok. They can go up to maybe 18, 20 GHz, ok whereas the cable that we have is no good for more than even a GHz. So, unique your specific specialized cables for them and these are wonderful equipment temperature stabilized extra.

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This is no other equipment from Anritsu which is also a company which just looks like this. I just wanted to give you a feeling across manufacturers. It also has multiple ports, all right, port 1, port 2, all right, it also has different connectors and it has Smith chat based plots extra, ok, so you could connect in theory a transmission line, you could connect some impedances, you could connect say filters, could connect different things that you want to make for these frequencies and analyze what is going on with with these equipments, ok. This is also probably equally expensive.

Nowadays, we are getting something of slightly lower specs.

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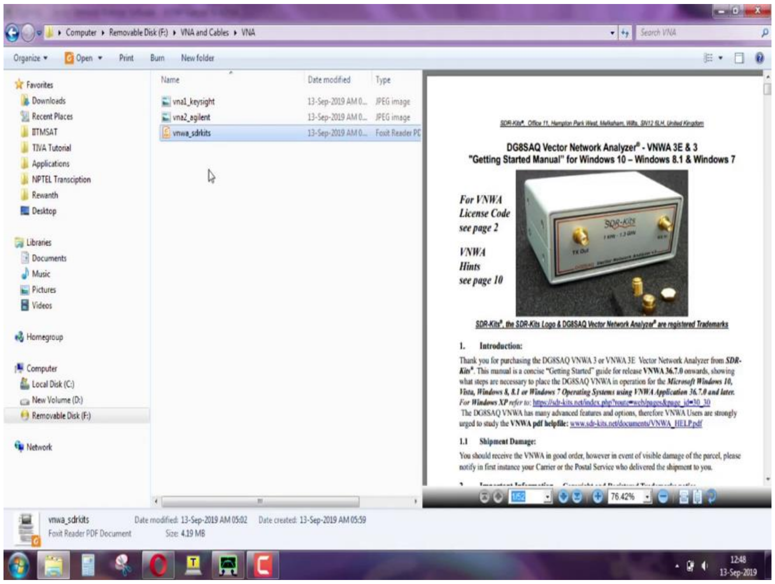

But something which I think really suits the studies in universities are these mini vector network analyzers.

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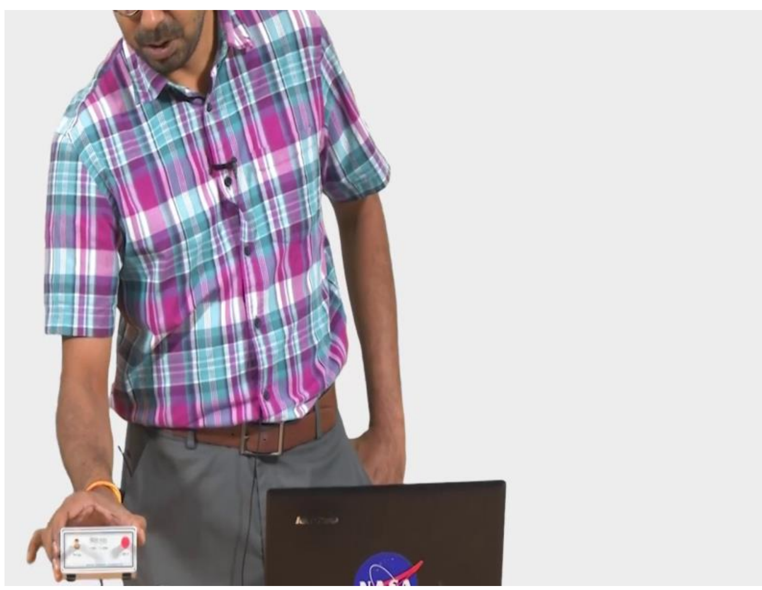

So, this is a mini vector network analyzer, ok. So, all it does is it takes in some input, it has a transmitter which sends out which is your source in our transmission line course and it has a port for a you know receiving the data. So, it has a receiver and then it has some processing and then it connects to your computer and it has its own dedicated software to show us what is going on.

So, this is all it is. All this big equipment that you saw has extraordinary abilities, but this is good enough for most of the day-to-day work for you at least for studies and for amateur radio enthusiasts extra. This is a very very good piece of equipment. To give you the cost comparison I gave you the cost of that to be about 60 lakhs in Indian currency, all right, this is about 500 to 600 US dollars, ok it is about 30000 rupees. So, it is an order of 100 lower than the cost of the big machines. So, I think for universities which are looking at you know having a curriculum for just doing some demo extra they can always purchase one or two of these and have some experiments going on. So, this is a mini vector network analyzer, all right.

In particular the one we have is made by SDR kits, it is a company I think based in the UK, all right.

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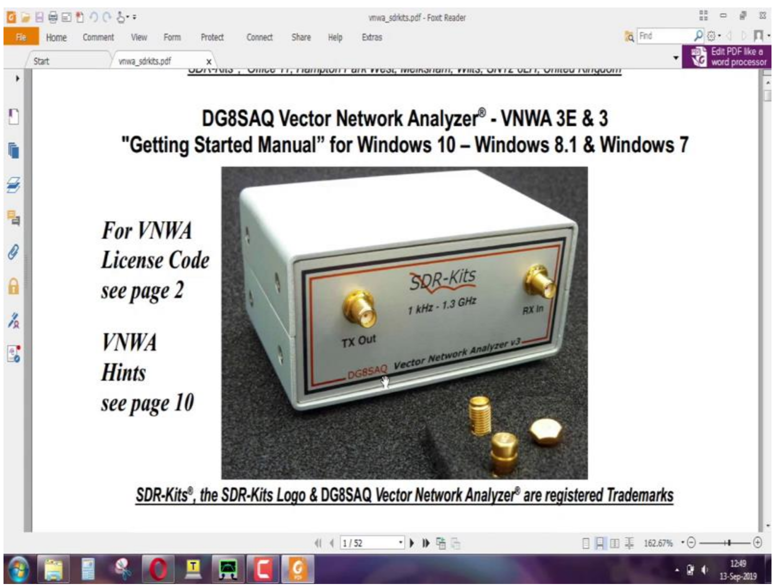

And so, this number that they have DG8SAQ is the amateur radio sign for the inventor, all right. So, DG8SAQ is a person who knows ham radio code. So, he is behind the design of this.

At the code it has some atmega microcontroller inside and then it has some circuitry, to sample, to convert extra, right. So, this is what it is, ok. I will quickly go to the part where it shows the circuit. We will not be able to make out much other than just understand that it is a you know simpler set up, but it is very very handy and very useful. It gives you detailed instructions about things.

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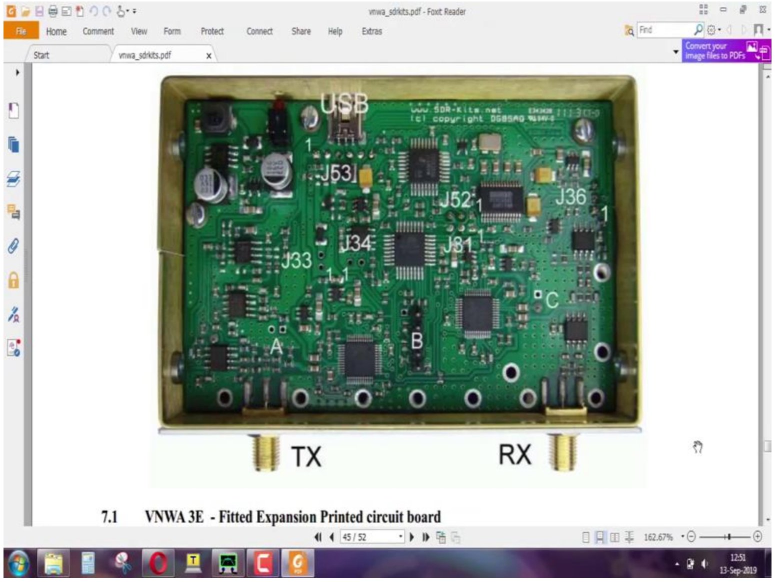

So, this is the board that is housed inside this box. I do not think we can read circuits just like that. But it is to just tell you that it is possible you know to make simple versions of very complicated vector network analyzers that may have porous specifications, but works just fine for most of the practical aspects for us to understand many things about transmission line, these kinds of things are good enough. So, it has an upper frequency range of 1.3 GHzThat is good enough for us to know to look at most of the transmission line problems. So, this shows that the transmitter and a receiver, all right SMA connectors which will be these parts over here, right. So, I think this is good enough and there are now many many more companies, there is a mini VNA at roughly the same price, so I think universities can procure this.

Now, what will we do? We will try to use this because I was told that these are transmission lines. Let us just see how it operates and what you can expect and whether we can confirm one or two things that we learnt from the class using this, right. You want to do it. So, this is the Smith chart screen of this equipment, all right. It is a mini VNA connected to the computer and they have their own software to run this, all right. So, it provides your Smith chart. This is something that we have generated on our own, all right and all right.

So, now I have nothing connected to this. So, I am going to remove these connectors, all right.

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So, it is an open circuit, all right. So, it is towards the edge. Now, you will notice that it is a little bit away, right it is not right in this place that is because every minute detail will start counting, all right. When you calibrate these devices, if you put something and you calibrate and say that this is an open circuit then that tiny detail matters. So, when we calibrated this we had this on ok, all right.

So, in practice every single connector and every single thing that you do actually really matters, otherwise you will have slightly different results. Also notice that we are running this for a single frequency because in the class we have not seen multiple frequencies, single frequency is all we have done. So, this is now your open circuit. Now, shall we connect a short circuit? So, so now, we are having a plate which will short the inner and the outer conductors, right. And if you look carefully there is a red colour marker that is appearing on your screen which moves to the extreme left of the Smith chart indicating that it is a short circuit, ok.

So, these are very simple things. Now, I think you can connect a 50 Ω load. Remember, that once again the connectors have changed, all right and this is a 50 Ω load and this Tx-Rx output is rated for 50 Ωs, ok. So, it should come at the middle, it is all it is right at the middle. So, it is impedance matched, ok. So, this is what. So, these are some small things we can do. Since, we are now seeing about the loads we can always connect a transmission line, ok.

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So, we will connect a SMA cable. Cable with an a SMA connector, I do not remember what cable this is, ok. So, it is an open circuit, all right, but you notice that the mark is not exactly over here because we know that depending on the length of the transmission line you will traverse around the Smith chart. It will go all the way from a short circuit, open circuit, at lambda over 2, it will keep repeating we know all that. So, now, we have a length of a transmission line that is giving you a position in the Smith chart over there. So, we can estimate only the electrical length. We cannot estimate the actual length of the transmission line. Now, just to make it abundantly clear what we can do is we can also add another section of the transmission line to this. So, he is adding a small section to it.

Total length.

Ok. So, he is having a different length, ok. It went to a different place. So, now, it should be clear that depending on the length of the transmission line, all right you will be travelling you know around in constant VSWR circles, ok. So, we are sweeping a constant VSWR circle. We could also go ahead and say that the load can be.

It is open, now we can short it.

No, no, ok you can short it. But shorting will again move in the constant VSWR circle analysis. But, we can connect a load because that is a.

Shall, put the load itself to.

Yeah, because it will be impedance matched. Should come to the centre, right.

Yes, yes.

If you need any connectors use this, all right, great, ok.

Almost.

Close, ok. So, impedance matching is a [laughter] not a joke, all right. And you know we are not doing it in the perfect ways either, all right. So, we are having a 50 Ω load and a the frequency that we are doing is

100 MHz.

100 MHz. It says something else over here.

(Refer Time: 28:24) 100 MHz.

Ok, 100 MHz. So, you know it's somewhere there, [laughter] all right. Suppose, I take this load and connect directly.

You can remove that also.

(Refer Time: 28:54). Close to the centre, [laughter] all right. You have to believe if I say that it is an impedance match, close to the r equal to 1 circle. Maybe we need to calibrate with the exact connector. So, in practice every minor detail will matter, but being the electrical engineer we are, let us deliberately do something, right.

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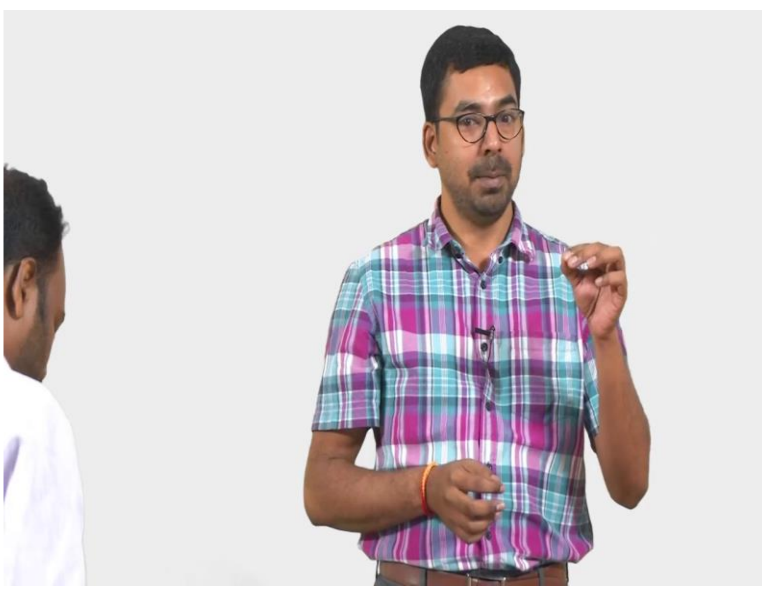

I have a couple of resistors, all right that I have you know braided together these are 200 Ω resistors. I think these are 200 Ω resistors.

Yes, 200.

So, in parallel I have connected them, so they should be 50 Ωs, all right and this is supposed to be 200 Ω resistors. So, it should be yeah connected in parallel and it should be 50 Ωs. But 50 Ωs at what frequency? Should be you know. So, usually when you buy 50 Ωs for very low frequencies or a DC, ok.

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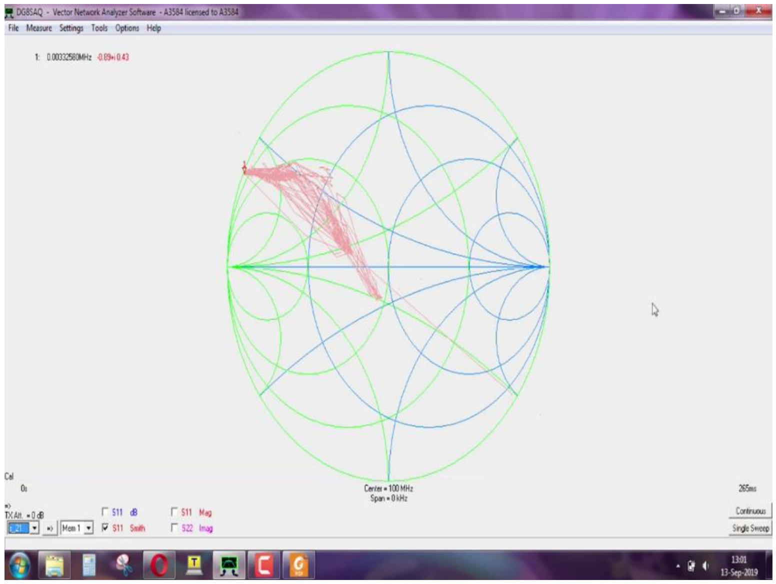
So, now we are connecting this to say a 100 MHz.

(Refer Time: 30:01) continuous.

(Refer Slide Time: 30:04)



What is this?

It is continuous volt, sir.

Huh.

It is around here.

Yeah.

Almost 50.

Almost there.

It is continuously sampling (Refer Time: 30:24).

Yeah, I think it is, ok, all right. But it is quite possible that at some other you can see the (Refer Time: 30:30) actually in the lower part of your Smith chart, maybe some parasitic capacitance is there. So, we never know what is going on.

One resistor, one resistor.

One resistor, ok. Problem is breeding is easy then unbreeding it.

Maybe one side it must (Refer Time: 31:03).

It will be very different because it will be open circuited on the other side, ok. First of all [laughter] nobody will do experiments like this, but you know for the sake of a class demo I am doing, but I do not think this would qualify as a research thesis or anything, but you know. It is somewhere else.

Yes.

But, you know these are all the small things that you can do. Actually, it is a lot of fun having a mini VNA and then you can do a lot of things. There was something we did with the open circuit and short circuit, right.

Yes.

Ok.

It is (Refer Time: 31:46).

So, currently I think the transmission line is open circuited, all right. This was a question that was asked. I wanted to determine the characteristic impedance of this. Open circuit it once, all right and then you have to find out the impedance; so, how do a, But you can notice that it is not on the horizontal axis, it is having a small amount of you know inductance. So, I want to get one.

Impedance.

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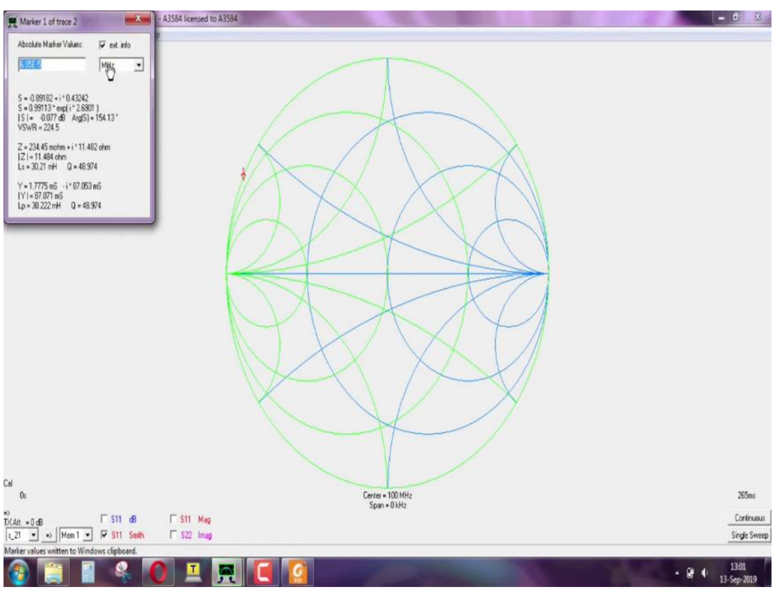

Yeah. So, it gives me an impedance of a $234.45\ m\Omega + j11.482\ \Omega$. So, this will be your short circuit impedance that you will see. So, this is Z_{OC} right and then we can connect the short circuit.

Open circuit this one.

Yeah, this is open.

And (Refer Time: 32:46) calculation.

Yeah, you could, you could.

(Refer Time: 32:49).

Yeah, you could take these values and calculate a square root.

(Refer Time: 32:54).

It is ok I think.

J (Refer Time: 32:58).

It is fine, it is fine.

J 11.

But the important thing is your characteristic impedance for open and short are supposed to have only like $jZ_0 tan(\beta l)$. It is not supposed to have a real part at all, but in practice, you get a tiny real part, but the imaginary part is much larger than the real part, all right. So, you will always end up with some tiny real part. Now, it is a short circuit, all right. It moves to the diametrically opposite point and if I wanted to measure the impedance, again you know the imaginary part is much higher than the real part, ok. So, then you can now use this for a number of other things. People using for antennas waveguide studies exclusively you know use this VNA. I think now you have a feeling that what you are studying can be converted to some simple experiments and you would be able to do them.

So, with that I think we will stop. The next class we will jump to the next topic, which is going to be transmission and reception in the case where you do not have any wires.