Introduction to Time – Varying Electrical Networks
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Motivation to learn about time-varying circuits and systems: Part 1

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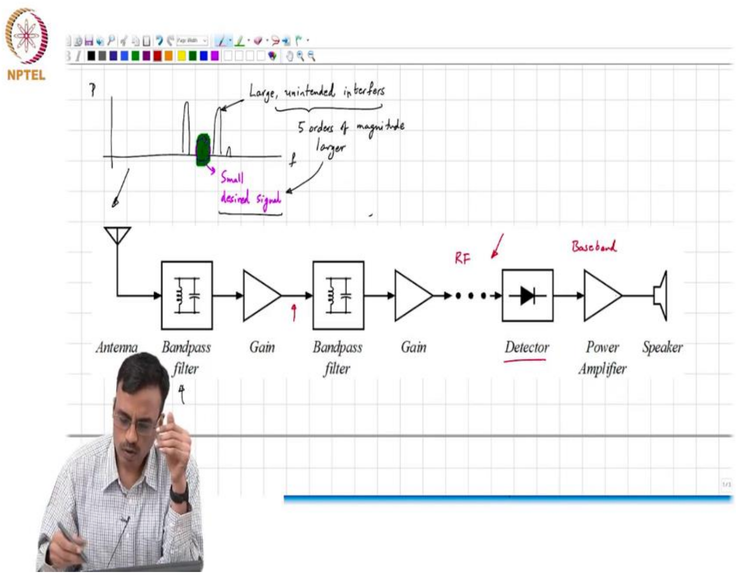

Good morning everybody, welcome to advance electrical networks. This is lecture 25, so today we will start learning about Time Varying Circuits and Systems and like everything else we will concentrate on linear time varying circuits and systems. So, before we get in to the details, I would like to address the first question you may have in your mind namely why should I learn about or why should I even care about time varying circuits?

And the answer is not far to come by well, if you look into your pockets, your cell phones are basically radios plus a whole lot of extras added and if you go back in time to motivate the need for time varying circuits if you go back in time and looked at say radio may be a 100 years ago, remember and this is what it would look like. The rf spectrum basically is as you are probably aware it consists of many signals, it is a crowded space and what you are interested in is perhaps a small desired signal.

And along with the small desired signal there is a whole lot of large unintended interferes and many of these larger unintended interferers can be 5 or 10 orders of magnitude larger than this small desired circuit. So, the job of the radio is to basically somehow get at the small desired signal from this mess of signals which are several orders of magnitude larger and you need to eliminate all those large signals and then somehow pick out the small signals and amplify it to a level that will be eventually you will be able to hear it with the human ear.

Now the question is, the first question that comes to mind is how why did I simply amplify the signal? Well, we need this chap, so why not I simply amplify the signal right away?

Student: (())(3:21)

Professor: Well, you have a small desired signal but there is a whole lot of undesired stuff which is very large compared to what you desired and if you amplify and the whole signal as is, then your amplifier is going to saturate because the interference are going to saturate the amplifier. So, it does not make sense to amplify the rf signal as is, what you need to do therefore, well you attempt to eliminate the interferers and amplify, once you eliminate, once the interferers are reduced and amplitude you can amplify a little bit. Then you can go and what do you call reduce the interferers a little more by further filtering and further amplification and so on and so forth.

So, that was the among the first ideas that was attempted to realize a radio. So, you have a bandpass filter and remember these filters are to be extremely narrow and as you have already seen in your assignments you know making a very high quality factor narrow band filter has a lot of implications with respect to noise. So, therefore, you want to make a high order bandpass filter, it does not make sense to put the entire bandpass filter right up front and then amplify the result and the reason is that as you have already seen, if you cascade the whole bunch of somehow make a very high order bandpass filter, you lose a lot of signal and the moment you lose signal it is equal to taking a hit in the noise factor.

So, what you want to do is, do some course bandpass filtering then you gain up the result to however large you can without saturating the amplifier, then now the signal here has got well is got the small desired I mean slightly amplified desired signal, but more importantly the difference between the interferers and the desired signal becomes smaller as a consequence of the bandpass filter up front. Does it makes sense?

And then well, I mean you need to get rid of the interferers further, so you put another bandpass filter some more gain and then you do this until I mean let say I have 10 stages of this what will happen eventually? Well, the equal and transfer function is that of cascading the whole bunch of narrow band filters and you know that if you have a filter like this and you cascade one more like this you basically will get the result which is narrower.

So, when you cascade the whole bunch of bandpass filters and amplify them up, so as far as the transfer function is concerned from here to here you have a lot of gain and very high order bandpass filter and the hope is that at the end of this rf receiver chain you basically end up with only the desired signal and then once you have the desired signal only you can detect its angular for instance by using some kind of nominate detectors a common thing to do those days was to use a diode I mean you know I am sure all of you have seen this, this is basically an envelope detector.

So, once you detect the envelope it is like you have base band signal here and then you have going to an audio power amplifier. So, this is all rf and this is all base band and you go into an audio power amplifier and then which drives the speaker.

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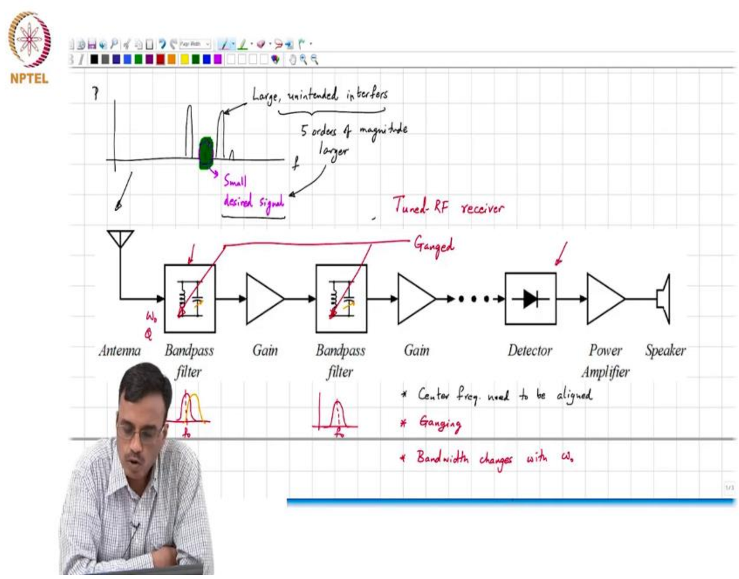

Now there were several you know nagging problems with this radio receiver. This is what was called the tuned rf receiver and there must have been some problems with this which motivated the search for better ways of doing accomplishing the same task. What do you think the problems host by this way of receiving radio signal are? What all do you think might be problematic?

So, one problem is that well all these bandpass filters better has better have their center frequencies lined up to the exact same value, it does not help if one filter is centered f naught in the neighbor is centered here. So, if you do that then you basically have, when you put kind of such things together you basically are not receiving anything at all. So, these were all made with inductors and capacitors and therefore, you needed to make them very very carefully so that when you made 10 of them or 15 of them, the center frequencies of those would be with the ideally of course would be identical in practice because of mechanical tolerances it is not possible.

The moment you do that the cost goes up and note me that you may tune them in the factory but you bring the radio set home well the center frequencies have drifted, so you would basically need to have some minor adjustment of each of these you try to bring the radio home and then carefully adjust some screws on each of those bandpass filters so that the station you hear is very loud. That brings us to the next problem, so this is of course problem 1 is center frequencies need to be aligned. What could be the next problem? Pardon?

Student: (())(10:24)

Professor: I cannot hear you. Yes.

Student: (())(10:27)

Professor: Well, it stands to reason that you know you are buying a radio to be able to listen to a whole bunch of stations, so if you want to listen to a different station what should you do? Well, you need to move or tune the bandpass filter to the next station and again you must make sure not only are these align for one station, the center frequencies must be aligned for all stations of interests. So, in other words, basically you have all these must be what do you call ganged together so that when you go and turn one nob the center frequencies of all these bandpass filters move exactly the same amount.

I mean it is hard enough to keep the center frequency identical even if you did not have to tune the bandpass filters, now over the entire AM range for instance which is fact of 2 to 1, you basically now reduce to, you now have the bigger problem of being not only matching the center frequencies but being able to tune them over a wide range while still matching the center frequencies. So, this ganging again as you can see is, all these are in principle doable but in practice when you finally you have to mash in these components and there are finite tolerances and to keep these tracking over temperature and so on is a real challenge. What next might be the problem?

Student: (())(12:16)

Professor: Well, I mean if you want low noise well you need inductors and for the bandpass filters. What comment can you make about, I mean if you want a narrow band filter the quality factor of each of these conductors and capacitors must be or the quality factor of that parallel RLC circuit must be some large value. Now if you tune the center frequency and the quality factor remains the same what comment can you make about the bandwidth?

Let us say the center frequency in radiance per second is omega naught in the quality factor is q. What is the bandwidth? Omega naught by q. Now if you suddenly let us say omega naught changes from one station to another let us say omega naught changes by 20 percent. What comment can you make about the bandwidth? Well the third problem is that the bandwidth changes with the center frequency, because q is largely constant across. Any other problem that you can think of?

Well that is happening here, I mean the demodulation is happening at the when you detect the envelope, well in those day’s people were not too worried about spectral efficiencies so you could not get away with nonlinear demodulation techniques like this is not optimal spectrally but that is okay in those days, of course now you have an a to d converter and then whole thing is done electronically because band is very expensive and you want to make sure you want to do whatever it takes to save bandwidth. But it is not a fundamental problem.

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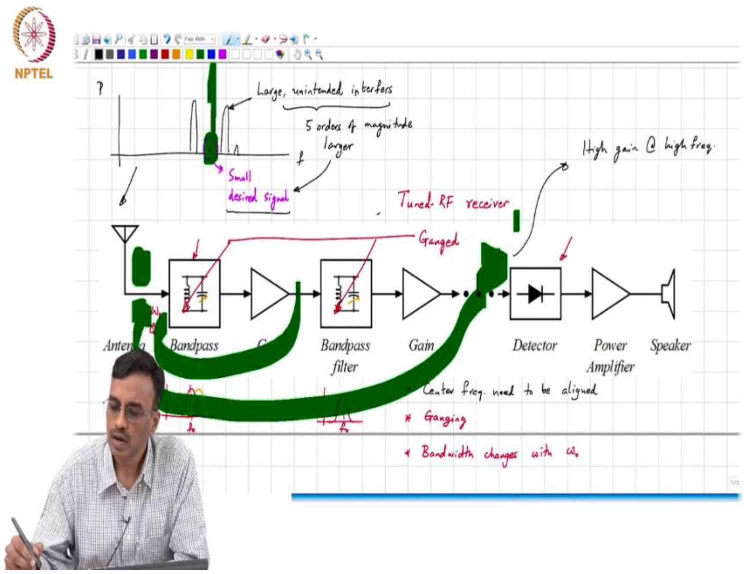

So, the next problem or a very important problem of this structure is the following. As we have already seen what comment can you make about the gain of that entire Rf chain? I mean is it very small or very large? Finally, when you go from here to here at the center frequency you find that the gain must be large enough to push this by several orders of magnitude. So, it is not uncommon to have a gain of 10 power 5 or 10 power 6 from the antenna to the output here and on top of that you have a cascade of, you not only have gain but you have a cascade of filters, so you have been affect a high gain system with a very very high order.

If you have I do not know if you have 6 filter stages, each stage is second order at least if you assume that the gains are have no frequency dependent and if you out 6 of these together you have a twelfth order system with a very very large gain, so what? No the reflection from the speaker is at what frequency? So, you have a high order, what about stability?

Student: (())(15:48)

Professor: Stability only as far as I can remember is only a problem when there is feedback. Yes, any other thoughts? I mean what issues? Yes (())(16:05) you were saying something. Well, fine I mean you know linearity is you got to make the amplifier is linear, you have a high gain and a high order system. So, what should you be worried about? When somebody says stability, which is stepping the right direction but in last checks stability is only a problem when you have a feedback too. So, why do you think it could be a problem here?

Any two points in space have only so much isolation, so whenever you build something there is always going to be some spurious feedback path. From everywhere to everywhere practical. Now these spurious feedback paths will basically have transmissions which are, which can be made very small by careful design but cannot be made 0. If the amplifiers gain is sufficiently small then the fact that you have a spurious feedback of say magnitude of 10 power minus 6, which I admittedly is a very very small amount of feedback.

If you have only a gain of 100 and you have feedback factor of say 10 power minus 6, the loop gain magnitude is how much? If you have a gain of 100 and the feedback factor of 10 power minus 6, what comment can you make about the loop gain? 10 power minus 4, so whatever the phase does, the close loop system will never become unstable. I mean you all of you agree that the now because of this spurious feedback you have a feedback system. The forward amplifier is gained unfortunately in this case has to be very large of the order say 10 power 6, 10 power 7.

So, what is your estimate of how much feedback you can tolerate before the system starts to oscillate? And what is the gain and what is won by the gain? So, if your gain is 10 power 6 and you have a high order transfer function in the forward path then you can tolerate roughly 10 power minus 6 in the as the feedback path gain before the system starts to oscillate or become unstable. Does it make sense? Because remember that you will not avoid this the magnitude of the loop gain becoming 1, because you have a high order system it is very easy to get that 180 degree phase shift between the input and output.

So, therefore, a problem with this high gain, this is therefore as you can imagine this signal chain gives high gain at high frequency, at high frequency is particularly difficult to get isolation. As frequency becomes higher, parasitic capacitance becomes two nodes the impedance of that parasitic capacitance becomes smaller, what do you call the voltage induced in an inductor due to parasitic feedback is dependent on di by dt and if at high frequency di by dt is larger and therefore, in general isolation between two ports can always be expected to degrade with frequency.

So, the tuned Rf receiver which was very popular in early attempts to making a radio had all these problems. So, you would first try to bring the radio home and tune each one of these bandpass filters until they all were in sync and then sometimes when you tuned across the frequency range the center frequencies would go out of sync and then you have to re tune them again and the designer of the radio had to be extremely careful to avoid or minimize spurious feedback and as the small spurious paths is not nearly a function of the components but also the enclosure in which it is put and whole lot of very very careful design had to be done and it was always kind of an art to basically be able to make this radio work in the presence of all these effects.

So, and going to higher frequency (())(21:01) is even more problematic simply because all these spurious feedbacks becomes an even bigger problem at higher frequency. So, these were all the challenges of what was called the tuned Rf radio or tuned Rf receiver.

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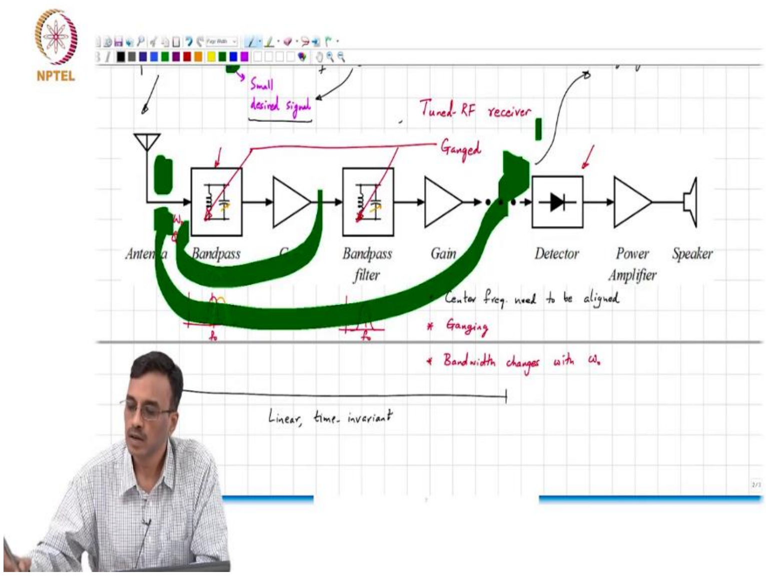

The key aspect of this whole receiver is a fact that up to here the receiver tries to be what kind of system? It tries to be linear, well I mean now that depends on how good you make your amplifiers. It tries to be linear and can you comment on whether it is time invariant or time variant? It is time invariant. Now let us fast forward to modern times.