Advanced 3G and 4G Wireless Communication
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Lecture - 25
OSTBCs and Introduction to V-BALST Receiver

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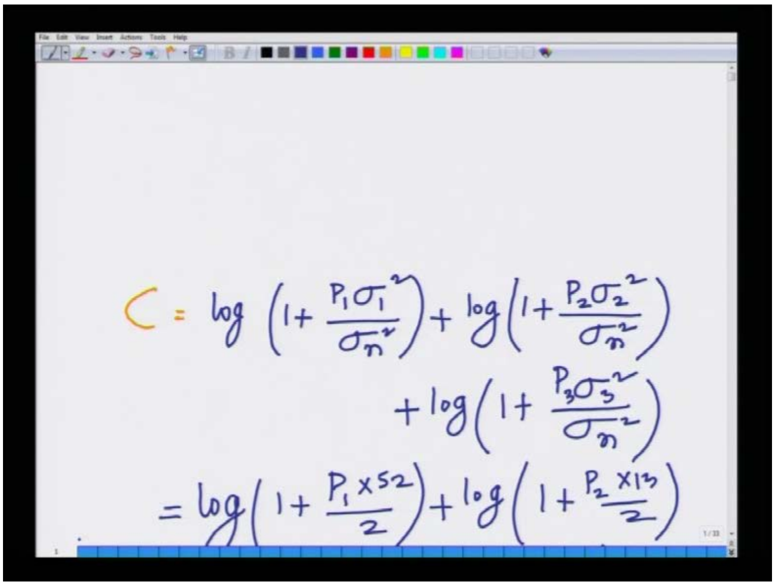

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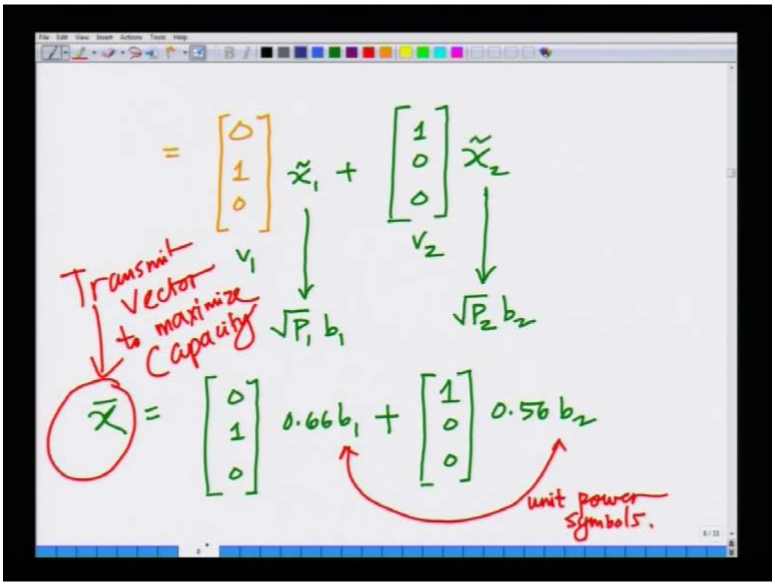

Hello welcome to the course on 3G, 4G wireless communication systems. In the last lecture, we completed the example on optimal MIMO capacity that is power allocation, optimal power allocation for MIMO capacity maximization. We in fact illustrated the power allocation, what was the different powers that need to be allocated and we also demonstrated the complete transmission scheme that is what are the symbols that are transmitted, and how are they pre coded and with what powers. I urge you to look at that example again to revise this concept of optimal MIMO power allocation or capacity maximization.

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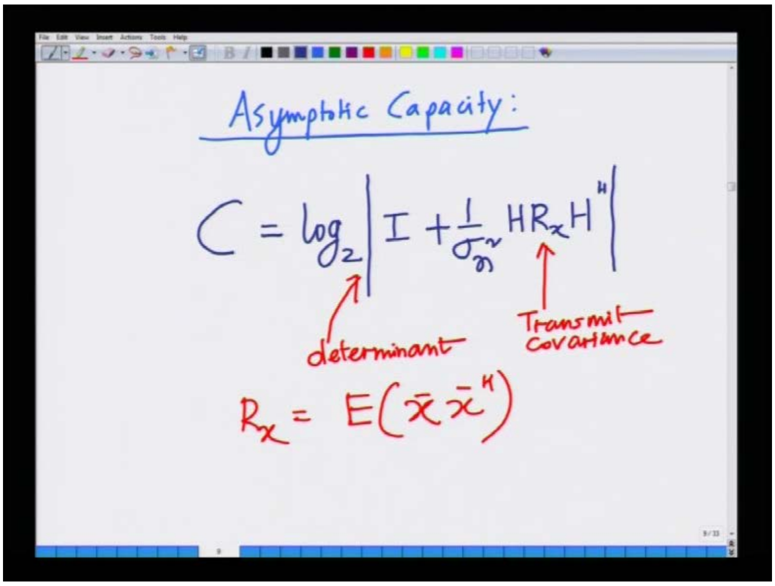

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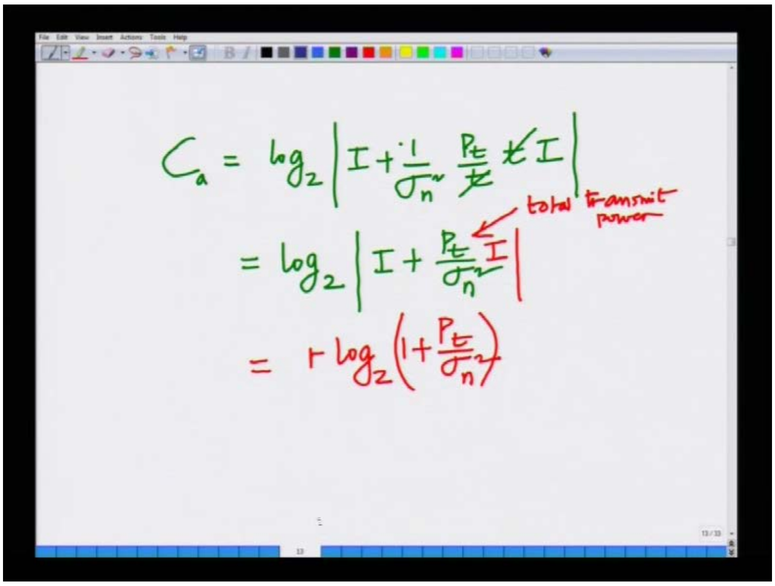

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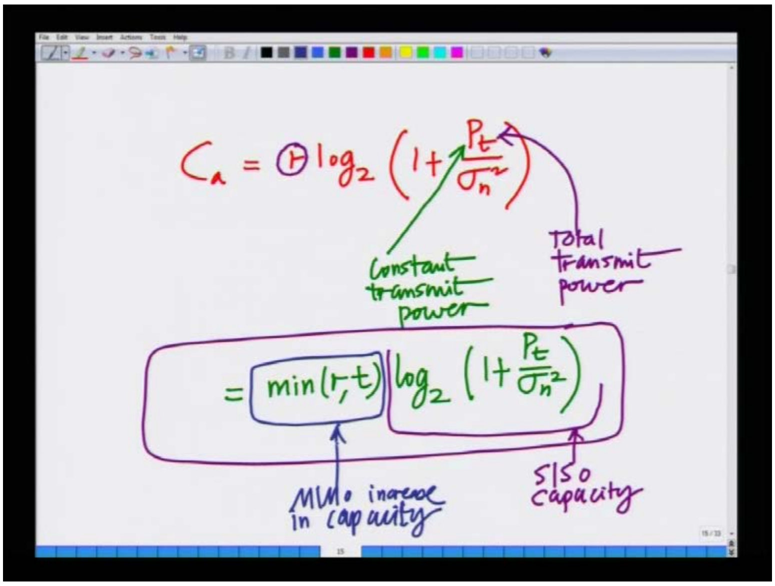

Next we started with an asymptotic capacity analysis of the MIMO communication system, and demonstrated that for a specific scenario as the number of transmit antennas progressively increases the capacity tends to r log 1 plus s n r, which can also be represented as the min of r comma t log 1 plus s n r. And we said the MIMO capacity scales as the minimum of number of r comma t, which is the number of receive antennas and transmit antennas, hence it increases linearly with the transmit power, that is that is the reason MIMO results in a significant throughput increase for the same transmit power.

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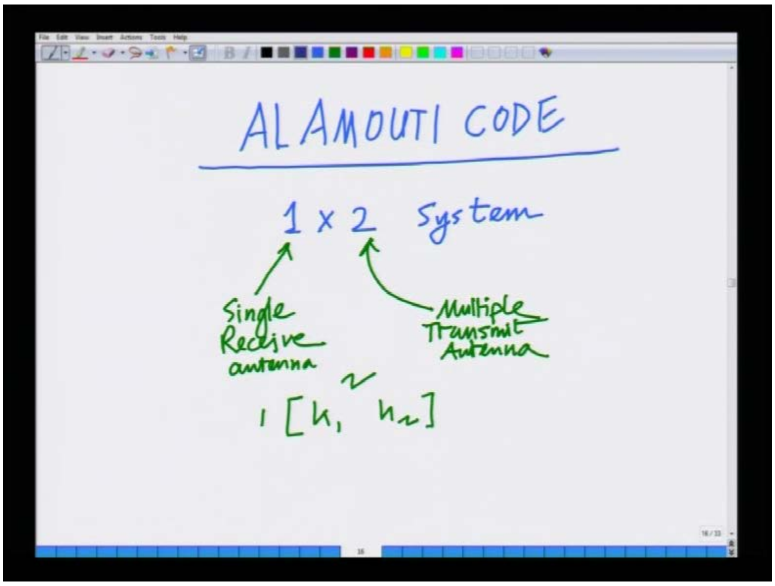

And next we proceeded to consider orthogonal space time block codes or the Alamouti code, which is a code designed for a 1 cross 2 system that is 1 receive antenna, 2 transmit antenna. Single receive antenna, 2 transmit antennas the channel coefficients are denoted by h 1, h 2.

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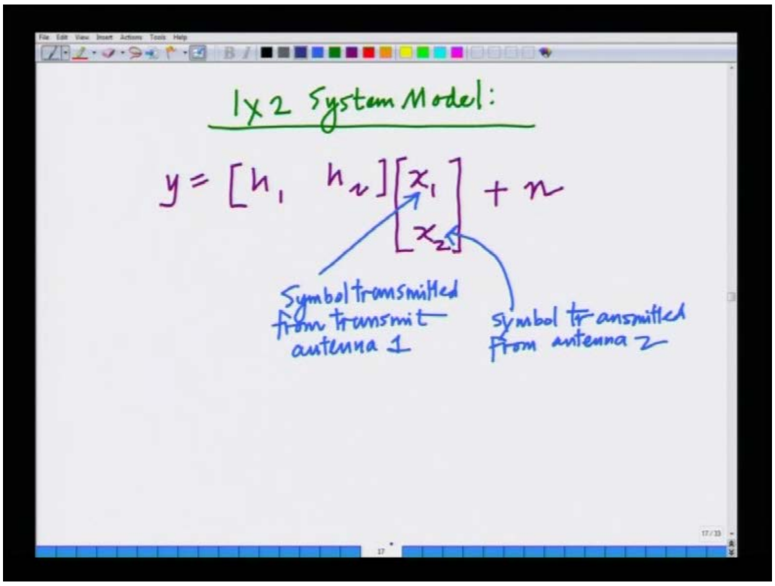

We said that in the first time instant, we transmit x 1, x 2. So the transmit, the system model is denoted as follows y equals h 1 h 2 into x 1 x 2 plus n. We said that if this h 1 and h 2 that is the coefficients, antenna coefficients are known at the transmitter, then I can transmit the vector such that x is the transmitted symbol, it is multiplied by the beam falling vector h 1 star or h 1 conjugate divided by norm h. h 2 conjugate divided by norm h times x. And you observe that using this scheme the s n r and the receiver is norm h square p over sigma n square; so I am getting the complete diversity order which is diversity order 2.

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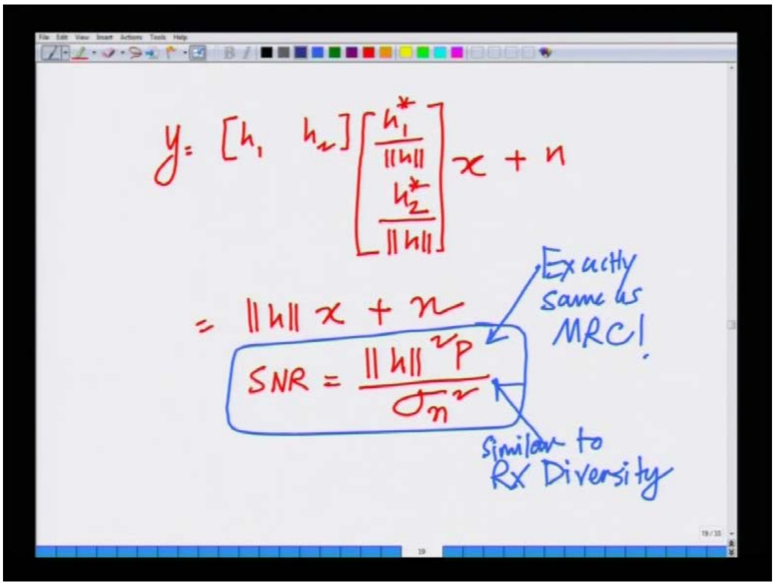

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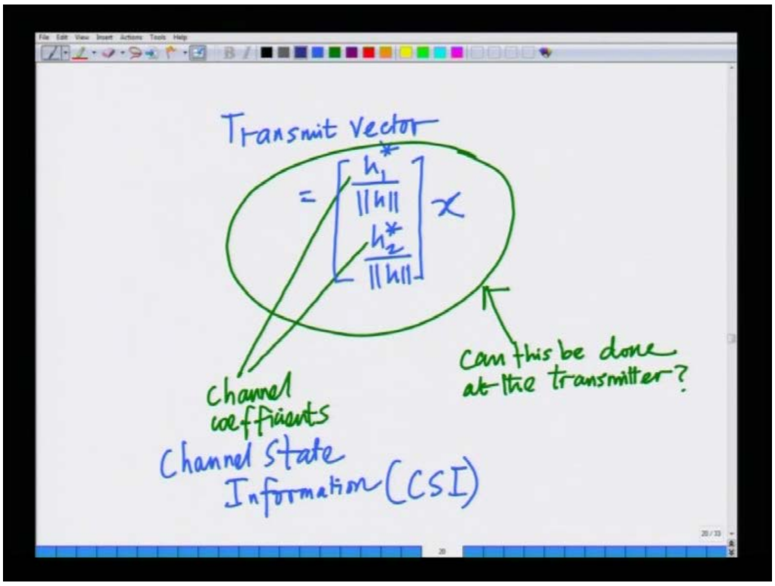

However the catch in this system is that these channel coefficients h 1 and h 2 need to be known at the transmitter for this schemes over that is that is not possible frequently in a wireless communication system. Hence we have to design alternative schemes to achieve transmit diversity without the knowledge of the channel coefficients or knowledge of the channel state information at the transmitter.

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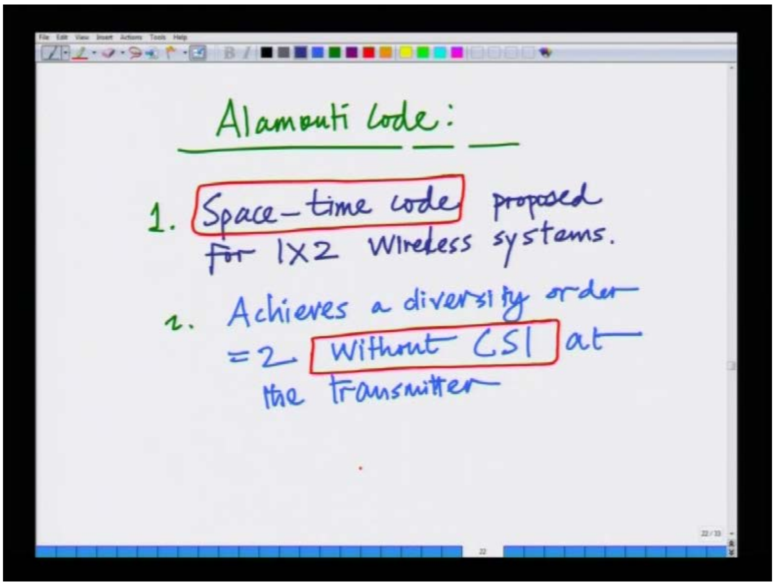

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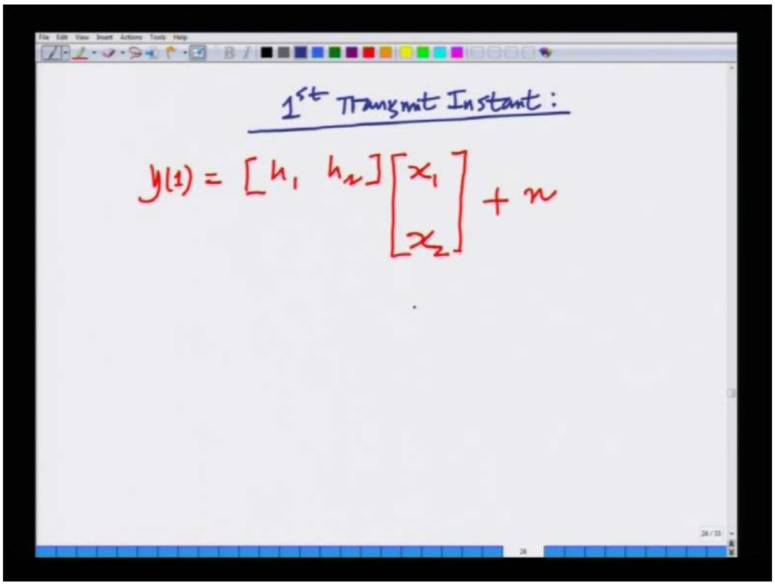

And the Alamouti scheme is one such scheme, it is designed for a 1 cross 2 MIMO system or 1 receive antenna 2 transmit antenna system and can achieve the complete diversity ordered 2 without knowledge of the channel coefficients at the transmitter. So we were starting to look at this, I went through the workings of this also namely we transmit x 1 x 2 two symbols x 1 x 2 across the transmit antenna. .

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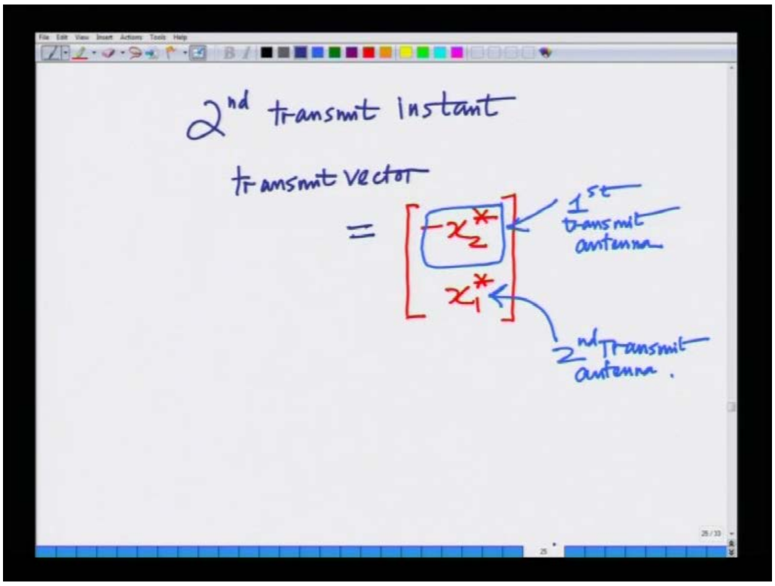

So the first instant and the next instant, we transmit minus x 2 conjugate, x 1 conjugate, since I was short of time last time, let us go over this again so as to enhance our understanding in regarding this.

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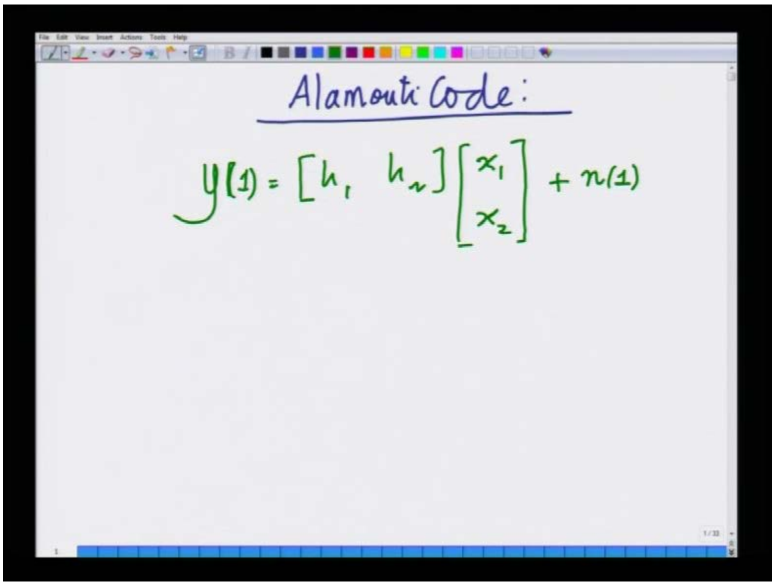

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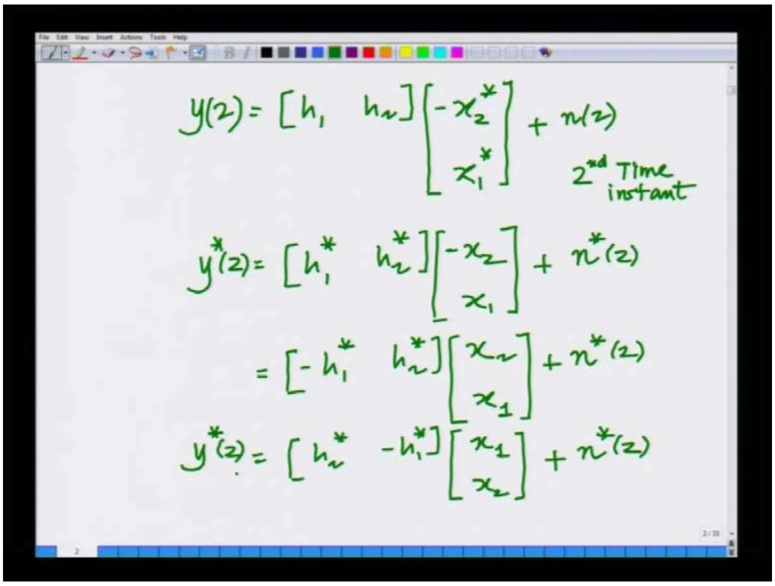

So the Alamouti code in the first instant this is the 1 cross 2 system, in the first instant I transmit x 1 comma x 2 plus this is noise. In the first instant I am transmitting x 1 comma x 2, in the second instant what I do is I shift the symbols I flip the symbols and I take the complex conjugate and take the negative of one of the symbols. So h 1 h 2 I transmit minus x 2 conjugate from the first antenna, x 1 conjugate from the second antenna and this is the second time instant, so this is the second time instant. I am transmitting minus x 2 conjugate where x 2 was transmitted previously from the second transmitted antenna. I am taking minus x 2 conjugate transmitting in the first transmit antenna. x 1 conjugate from the second transmit antenna, where x 1 was previously transmitted from the first transmit antenna in the first time instant.

Now what I do at the receiver I am going to consider y conjugate as a receiver processing, then this system can be represented as h 1 conjugate h 2 conjugate minus x 2 x 1 with simply the conjugate of each quantity in conjugate 2. This can also be now instead of having a minus sign in minus x 2 this minus sign can be absorbed in minus h 1. So this can also be written as minus h 1 conjugate h 2 conjugate x 2 x 1 plus n conjugate of 2 and this can also be now instead of having x 1 x 2 I can reverse the order of this symbols here, remember this is not reversing the transmission but simply reversing the mathematical order of consideration which means these coefficients get reversed over here. I can replace this as h 2 conjugate minus h 1 conjugate x 1 x 2 plus n conjugate 2.

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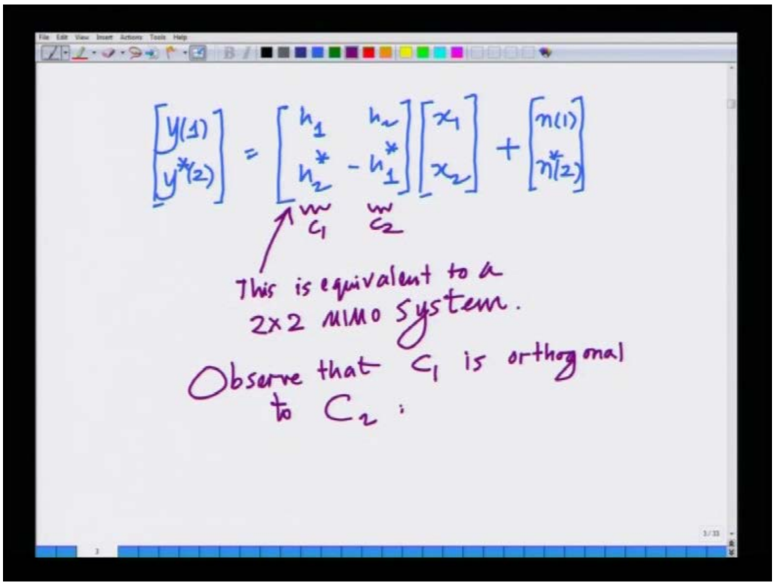

So I have reduced this transmission in the second instant to this form and now I can combine these by stacking y 1. You can see that the net system model can be expressed as follows that is simply h 1 h 2 conjugate h 2 minus h 1 conjugate x 1 x 2 plus n 1 n 2 conjugate. So I have reduced so this Alamouti the this 1 cross 2 system with this transmission of x 1 x 2 in the first time instant and minus x 2 conjugate x 1 conjugate in the second time instant can be succinctly represented by this net system model at the receiver by stacking y 1 and y 2 conjugate and this is c 1, this is c 2. Observe that this is now equivalent to a 2 cross 2 MIMO system. This is equivalent to a 2 cross 2 MIMO system. In fact observe that column 1 is orthogonal column 2.

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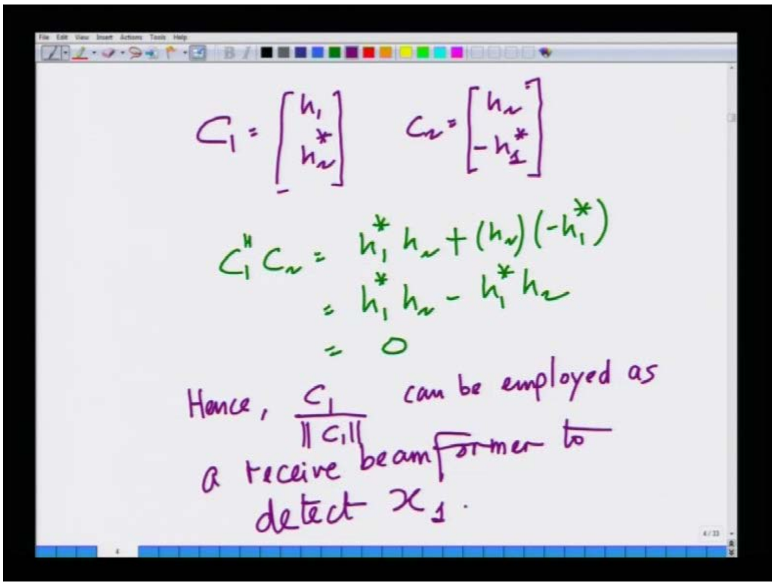

In fact you can observe that column 1 is orthogonal to column 2. Let us check that column 1 is nothing but, h 1 h 2 conjugate, column 2 equals h 2 minus h 1 conjugate and hence column 1 Hermitian column 2 equals h 1 conjugate times h 2 plus h 2 minus h 1 conjugate. This is equal to h 1 conjugate h 2 minus h 1 conjugate h 2, which is 0. Hence you can observe that column 1, c 1 Hermitian c 2 is 0. Hence these two columns are in fact orthogonal in this MIMO system, in this equivalent 2 cross 2 MIMO system, which the Alamouti coding scheme has been reduced to the two columns are orthogonal. So the two columns are orthogonal. Hence in fact hence c 1 divided by norm of c 1 can be employed as a receive beam former to detect x 1, hence c 1 by norm of c 1 that is the first column can be employed as a received beam former to detect this symbol x 1.

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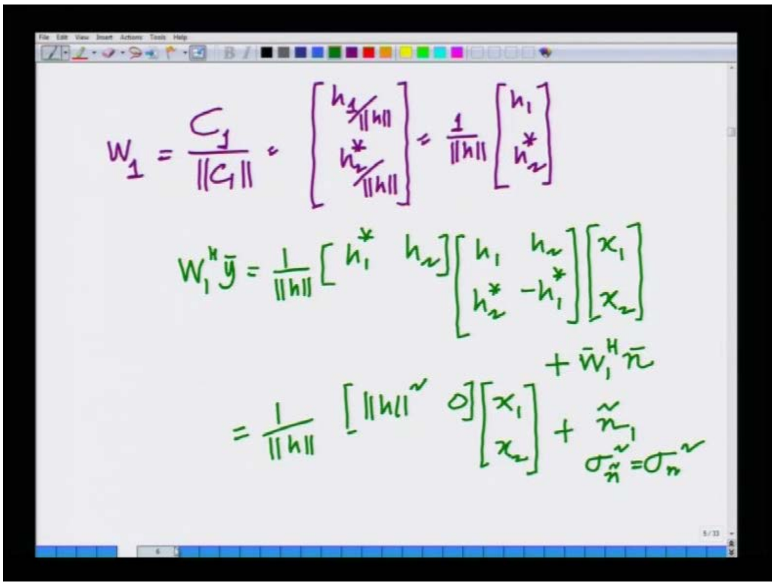

For instance let us take a look at it, c 1 divided by norm of C 1, norm of C 1 is nothing but, h 1 divided by norm of h and h 2 conjugate divided by norm of h, which is nothing but, 1 by norm of h h 1 h 2 conjugate. We can also denote this as the beam former w 1. So w 1 is nothing but, h 1 h 2 conjugate that is column 1 divided by norm of column 1. Now that norm of column 1 is nothing but, norm of the vector h 1 h 2 conjugate, which is nothing but, norm of the vector h 1 h 2, which is nothing but, norm of the vector h, where h is the vector h 1 h 2. For convenience we can represent it as norm of h since it is the same quantity.

Hence, looking at w 1 Hermitian y bar the system can be represented as 1 over norm of h w 1 Hermitian is nothing but, h 1 conjugate conjugate of h 2 conjugate which is h 2 times the system which is h 1 h 2 conjugate h 2 minus h 1 conjugate times x 1 x 2 plus w 1 Hermitian n bar. So what I am taking is that at the receiver I am taking this y 1 y 2 conjugate which I am calling y bar that is I stacked, remember y 1 y 2 conjugate to risk to get the equivalent 2 cross 2 Alamouti system model. I am receive beam forming using w 1 using w 1 which is the receive born beam former. So I am multiplying by w 1 Hermitian. You can see we earlier said w 1 Hermitian w 1 is derived from column 1.

Hence it is orthogonal to column 2. So this nothing but, 1 by norm h times you can see this is h 1 h 1 conjugate plus h 2 h 2 conjugate, which is magnitude h 1 square plus magnitude h 2 square which is norm h square and this is of course, 0 as c 1 is orthogonal to c 0 into x 1 x 2 plus n 1 tilde. I am calling w 1 Hermitian n bar as n 1 tilde, since w 1 is a unit vector you can ensure that the noise variance is preserved the noise variance is nothing but, sigma n square. You can verify that sigma n tilde square is sigma n square, this we have done several times before.

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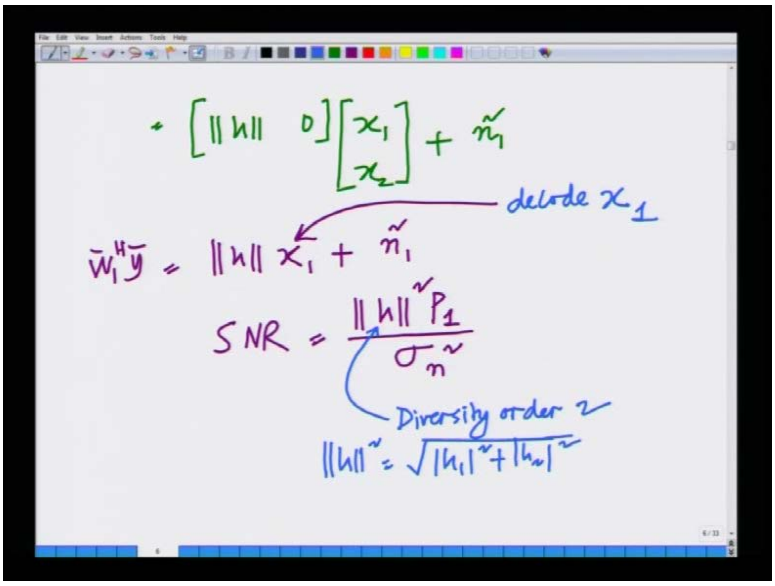

Hence this equivalent system model, look at this, this is nothing but, norm h square divided by norm h. So this is nothing but, equals norm h comma 0 into x 1 x 2 plus n 1 tilde. This is nothing but, norm h into x 1 plus n 1 tilde, this is after beam forming y w 1 w 1 bar that is using beam former w 1 bar. So I am doing as I am multiplying by w 1 bar Hermitian and you can see now that the s n r at the receiver is nothing but, norm h square p 1 divided by sigma n square.

So I can use this first I can use this to because this is free from x 2 I can use this to decode x 1. The s n r is norm h square p 1 by sigma n square observe that there is a norm h square in the numerator. Hence this results in diversity order, because norm h square is nothing but, magnitude h 1 square plus magnitude. This is square root of magnitude h 1 square plus magnitude h 2 square. There are two fading coefficients h 1, h 2 similar to maximum ratio combiner. Hence this has a diversity order of 2, since this scheme has a diversity order of 2.

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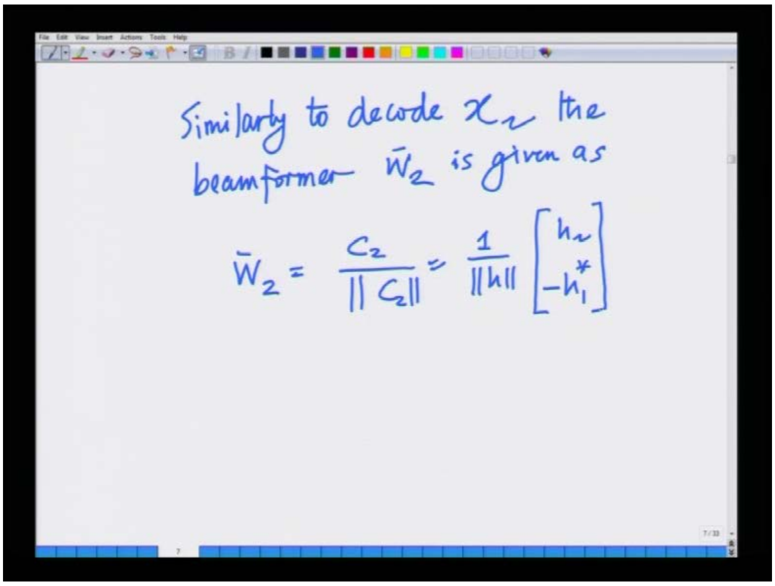

Similarly, to decode x 2 the beam former w 2 is given as w 2 bar that is to decode x 2 the beam former w 2 bar is given as w 2 bar equals c 2 divided by norm of c 2, the beam former w 2 bar is given as c 2 divided by norm of c 2, which is again nothing but 1 by norm of h times h 2 minus h 1 conjugate. You can verify that this is in fact the beam former which is orthogonal to again column 1, because the columns are orthogonal. So this beam former is orthogonal to column 1 and helps decode the symbol x 2, alright. So this is again this is again similar to what we did earlier.

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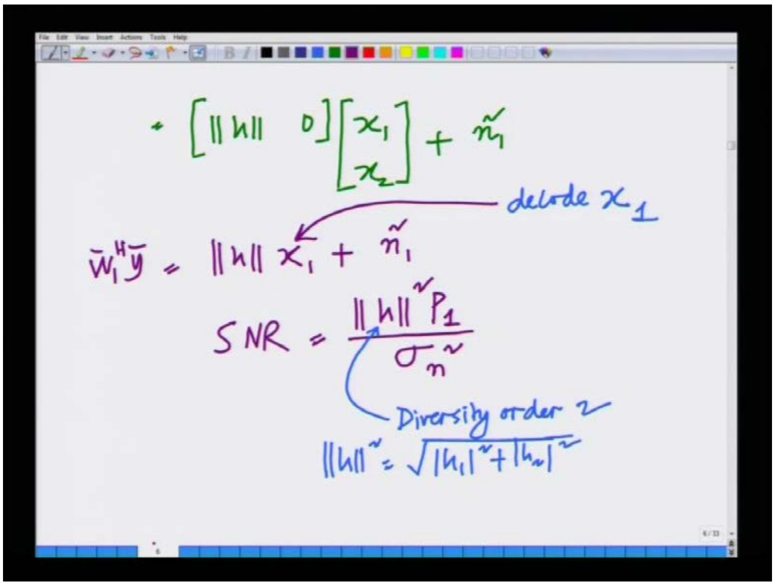

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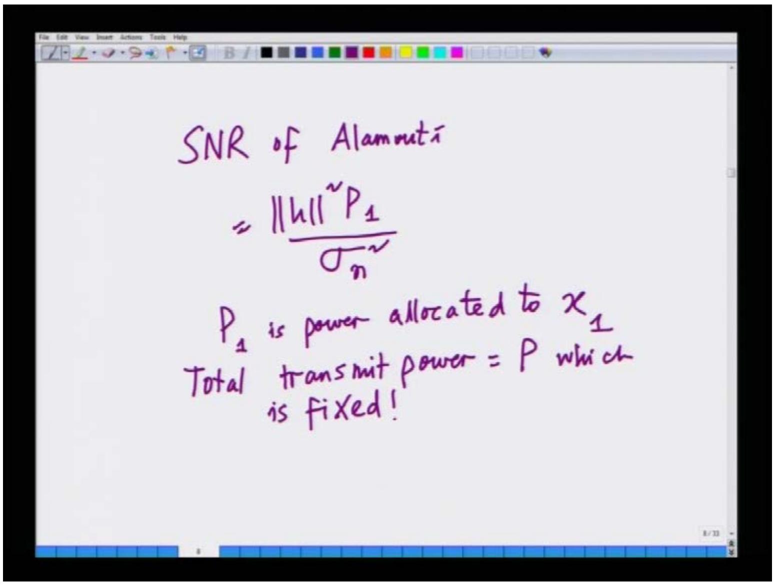

Now let us look at a basic example or before we look at a basic example first let me go back to the s n r of this Alamouti system the s n r of this Alamouti system we said is norm h square p 1 by sigma n square. So SNR Alamouti equals norm h square p 1 divided by sigma n square where p 1 is where p 1 is a power allocated to symbol x 1. Now remember the total transmit power is p t, so total transmit power is p which is fixed.

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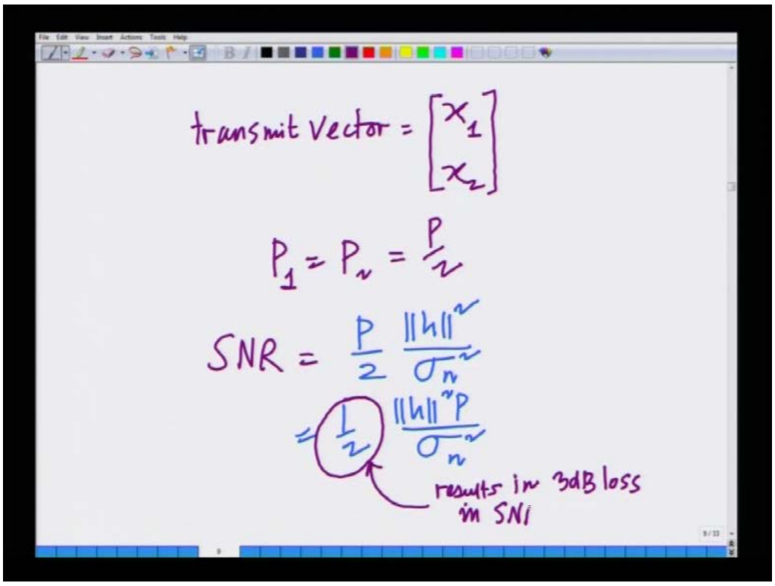

Let total transmit power remember our transmit vector, the transmit vector is nothing but, x 1 x 2, alright; which means there are two symbols that is being transmitted every instant of time; which means the transmit power has to be split between these two symbols. Hence p 1 equals transmit power of x 1 equals p 2 equals transmit power of x 2 equals p by 2, hence the transmit power is split, which between each of these streams as p over 2; which means the s n r equals p over 2 norm h square divided by sigma n square, which is nothing but, half norm h square p over s n r square.

Hence you can see that Alamouti code achieves the diversity that is second ordered diversity without channel knowledge at the transmitter, however you pay a price that price is this factor of half which results in 3 d b loss in s n r. This 3 d b loss in a s n r is compared to either maximal ratio combining that is having multiple antennas at the receiver or in fact having channel knowledge at the transmitter. That is if you knew the channel knowledge at the transmitter you can again beam form in the direction h 1 divided by norm h h 2 divided by norm h, remember to get the same gain as a m r c. However this are Alamouti code, it gives you the diversity order which is more important in a wireless communication system; however results in a three d b loss in s n r.

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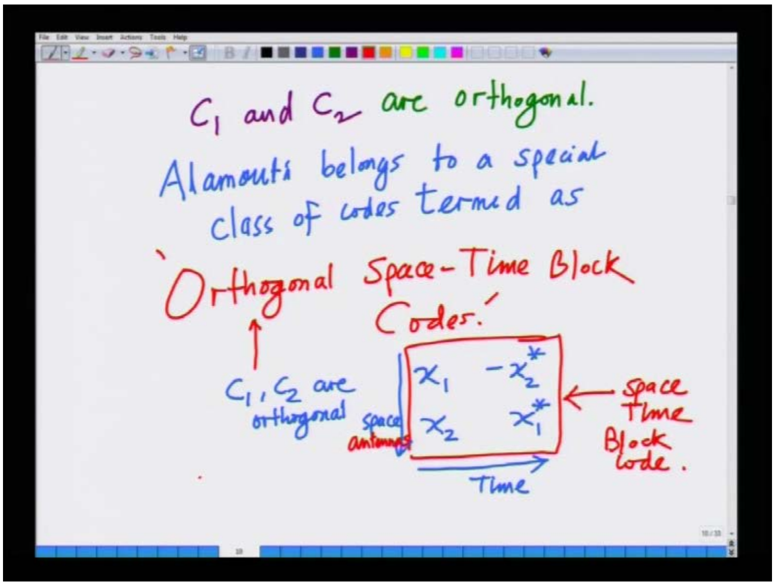

So this is the 3 d b the loss in s n r which is the price that has to be paid to gain diversity without knowledge of the channel at the transmitter. As you can see the columns c 1 and c 2 are orthogonal this is not a coincidence, this is by design of the Alamouti code this is a special property of such codes. The Alamouti code is belongs to a special class of codes known as orthogonal space time block codes. So let me elaborate on each aspect, Alamouti to a special class of codes termed as orthogonal space time orthogonal space time block codes, right. Why orthogonal because observe that the net c 1 comma c 2 are orthogonal, why space time because observe it is coding across space and across time. If you observe we transmit x 1 x 2 in the first time instant, x minus x 2 conjugate x 1 conjugate in the second time instant. So this is time and this is space that is across the transmit antenna.

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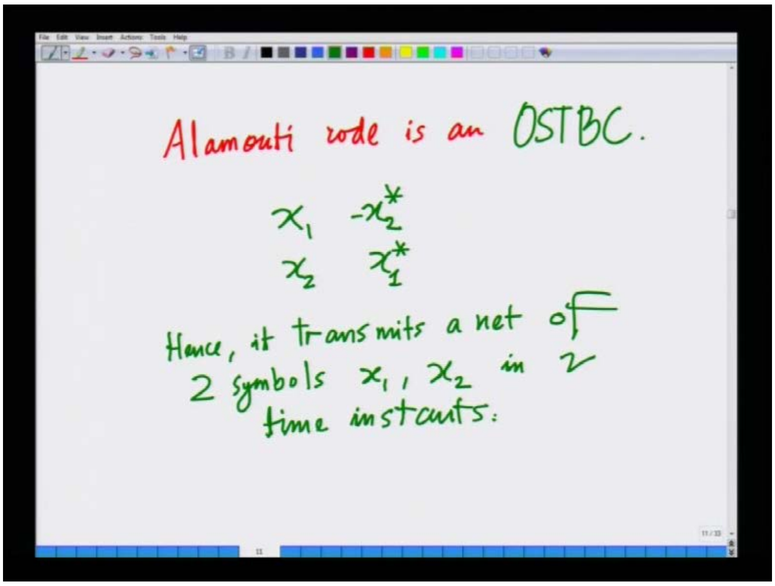

So there are two dimensions to it, one is across space, the other is across time this is the antennas. Hence this is a space time and there is a block of symbols, it is done using a block of symbols hence it is a space time block code. Hence Alamouti belongs to a special class of codes termed as space time block codes or orthogonal space time block codes abbreviated as OSTBC. Alamouti code is an OSTBC where OSTBC stands for orthogonal space time block code. further observe that Alamouti transmits x 1 Alamouti code transmits x 1 x 2 in the first time instant, minus x 2 conjugate x 1 conjugate in the second time instant, hence it transmits a net of two symbols x 1 comma x 2 in two time instants it transmits a net of two symbols in two time instants.

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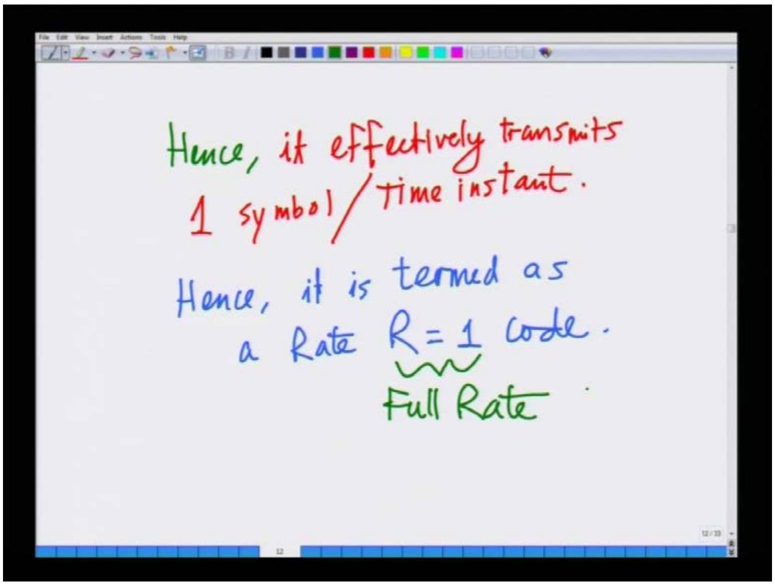

Hence it effectively transmits it effectively transmits one symbol per time instant, that is it transmits x 1 x 2 across two symbol instances. So if you see the net rate which is 2 over 2 time instants which is one symbol per time instant hence, this is termed as a rate 1 code, hence it is termed as a rate r equals 1 code. Hence Alamouti code is essentially termed as a code space time block code orthogonal space time block code with rate equals 1. This is also, sometimes said as full rate this is also termed as full rate code, that is rate equals 1 is also termed as a full rate code. So Alamouti is a full rate O S T B C that is the correct way to describe Alamouti code which is a full rate or orthogonal space time block code.

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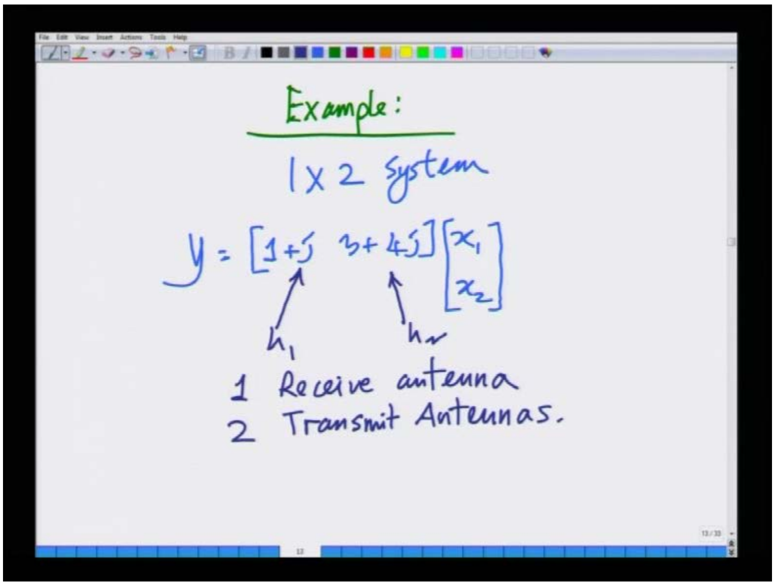

Let us take an example of the Alamouti code, let us take an example, I want to consider a 2 cross 1 cross 2 system, given by the following system model that is y equals 1 plus j, for this example I will ignore noise just to illustrate how the columns are orthogonal and how the decoding is done. I am going to ignore the effect of noise. So this is my 1 cross 2 MIMO system this is my 1 cross 2 system this is h 1, this is h 2, these are the two channel coefficients h 1 and h 2. h 1 is between first transmit antenna and receive antenna, h 2 is between second transmit antenna receive antenna. Remember there is single transmit single receive antenna, there is one receive antenna and two transmit, remember there is one receive antenna and two transmit antennas in this system which means I can write this as the first transmission remember we are transmitting x 1 and x 2.

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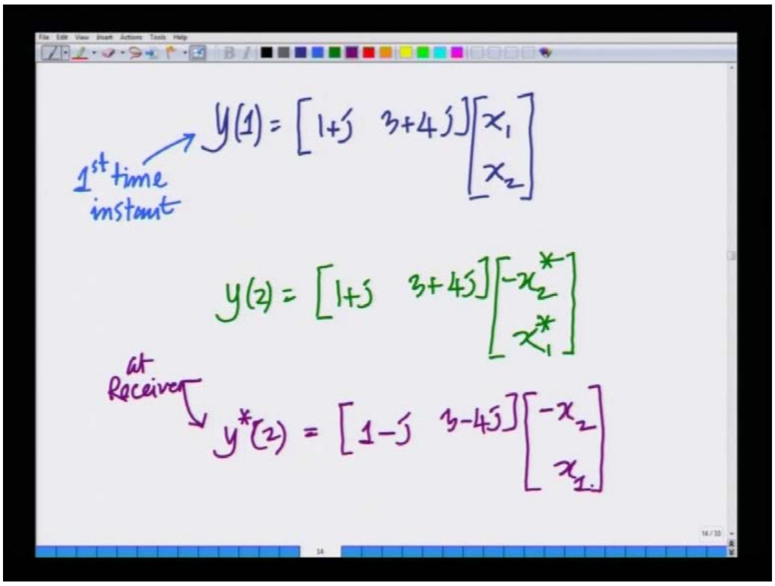

So I can write this as y 1 equals 1 plus j 3 plus 4 j into x 1 and x 2 this is the first time instant this is the first time instant, in the second time instant remember I am transmitting minus x 2 conjugate x 1 conjugate, hence this is channel 3 plus 4 j minus x 2 conjugate x 1 conjugate. I can take y conjugate 2 at the receiver, so this is done at receiver remember the operation of conjugation that is the operation of taking y conjugate 2 conjugate of y 2 is being done at the receiver this is nothing but 1 that is h 1 conjugate 3 minus 4 j which is h 2 conjugate into minus x 2 x 1.

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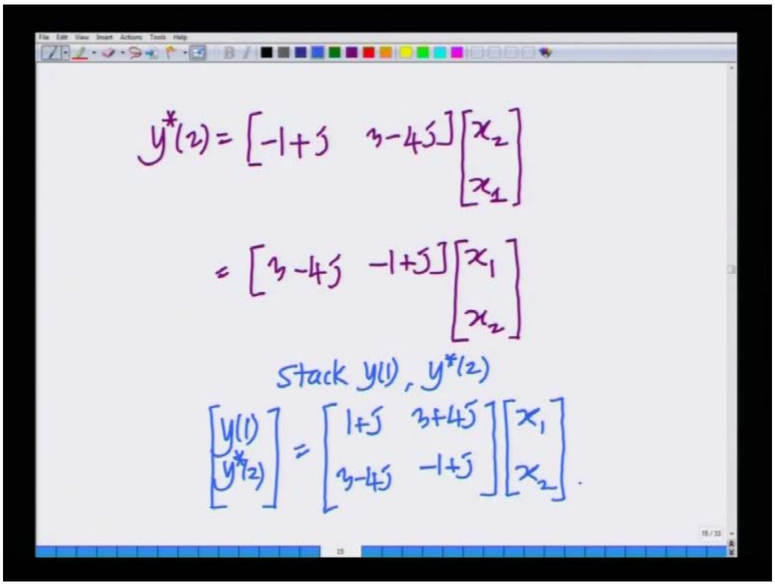

Now we will shift the minus sign from x 2 into the channel which is simply a way of writing it, this is not nothing to do with. The transmission it is simply a way of expressing this equivalent way of expressing this, this can be represented as y conjugate 2. So the minus symbol from x 2 goes through the goes to the channel coefficient which is minus 1 plus j 3 minus 4 j x 2 x 1. And finally, now I flip the order of x 1 x 2, that is not I am I am not flipping them during transmission, this is just simply an equivalent way of expressing them. This becomes 3 minus 4 j minus 1 plus j x 1 x 2 alright. Now I can stack y 1 and y 2 conjugate stack y 1 comma y conjugate 2 y 1 comma y conjugate two that gives me 1 plus j 3 plus 4 j 3 minus 4 j minus 1 plus j x 1 x 2.

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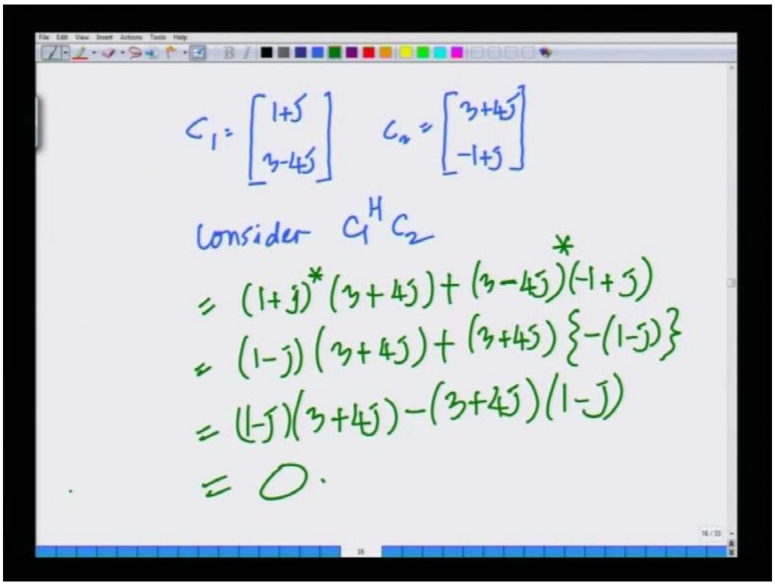

So now as a net result that I have taken y 1 I have done some manipulation on y2 conjugate, I have stacked y 1 y 2 conjugate that net system is this 1 plus j 3 plus 4 j 3 minus 4 minus 1 plus j into x 1 x 2. Now you can see column 1 equals 1 plus j 3 minus 4 j, column 2 equals 3 plus 4 j minus 1 plus j. Now, you can see column 1, column 2 are orthogonal. For instance if I take c 1 Hermitian c 2 consider c 1 Hermitian c 2 if I consider c 1 Hermitian c 2 that is nothing bu, 1 plus j conjugate into 3 plus 4 j plus 3 plus 3 minus 4 j conjugate into minus 1 plus j, which is 1 minus j into 3 plus 4 j plus 3 plus 4 j into minus of 1 minus j. This is nothing but 1 minus j 3 plus 4 j minus 3 plus 4 j into 1 minus j this is 0.

So c 1 c 2 are orthogonal, in fact we knew that because we proved it rigorously from the structure of the Alamouti system, that is when you stack y 1 and y 2 and some rearranging suitable rearranging of the terms we know that c 1 is orthogonal to c 2.

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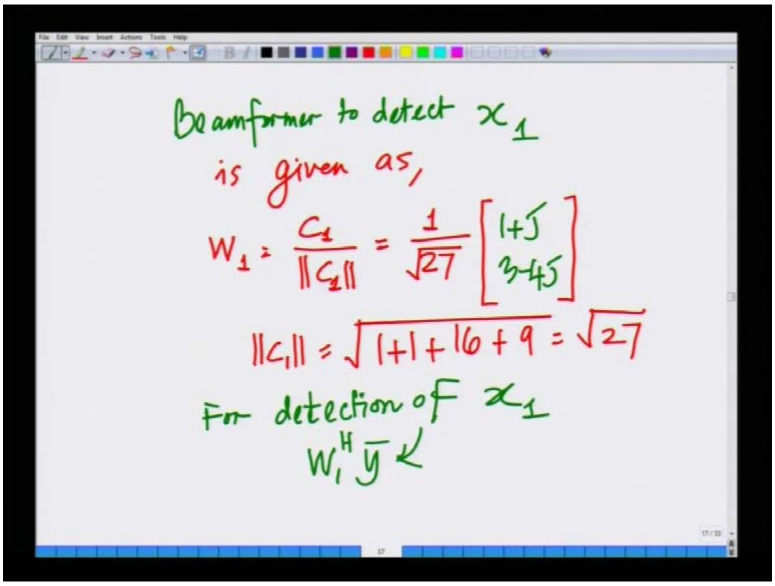

Hence the beam former for w 1 the beam former to detect x 1 the beam former to detect x one is given as w 1 equals c 1 divided by norm of c 1 which is equal to 1 over square root of 27 3 plus 4 j minus 1 plus j.

You can verify that norm of c 1 is nothing but square root 1 plus 1 plus 16 plus 9 equals square root of 27. Hence w 1 equals c 1 divided by norm of c 1, that is 1 over 27 root square root of 27, 3 plus 4 j minus 1 plus j decode detect for detection of x 1 you simply perform w 1 Hermitian y bar, for detection of x 1 you simply perform w bar Hermitian y bar. I am sorry this is actually so c 1 is 1 plus j 3 minus 4 j, so c so w 1 is 1 plus j 3 minus 4 j that is c 1 divided by norm of c 1, norm of c 1 is same thing square root of 27 and to decode x 1 I employ w 1 bar Hermitian y bar.

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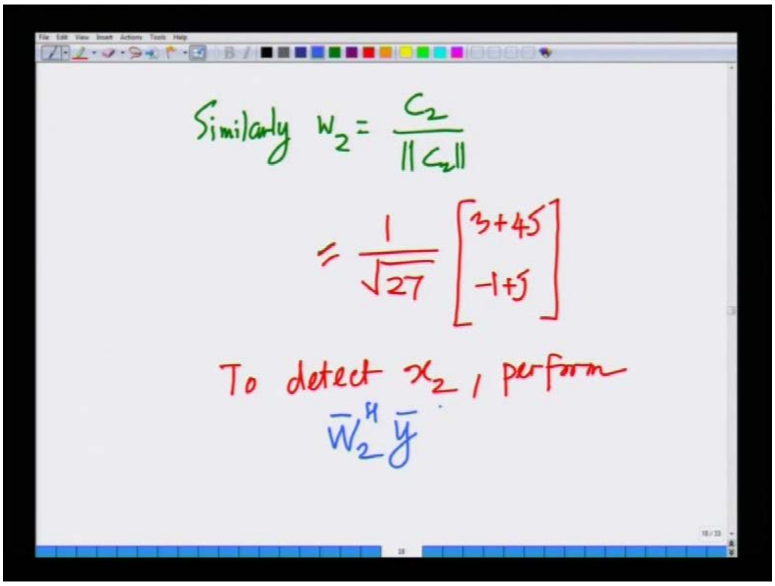

Similarly w 2 equals c 2 divided by norm c 2 which is nothing but, from this 1 over square root of 27 3 plus 4 j minus 1 plus j divided by square root of 21, and to detect x 2 we have to perform w 2 Hermitian y bar and that can be used. So one can perform so c 1 and c 2 are orthogonal columns in the equivalent 2 cross 2 MIMO system of the orthogonal space time block code Alamouti code, so w 1 can simply be derived as c 1 divided by norm of c 1, w 2 can be simply derived as c 2 divided by norm of c 2 and to detect x 1 one can perform c 1 w 1 Hermitian y bar, to detect x 2 one can perform w 2 Hermitian y bar.

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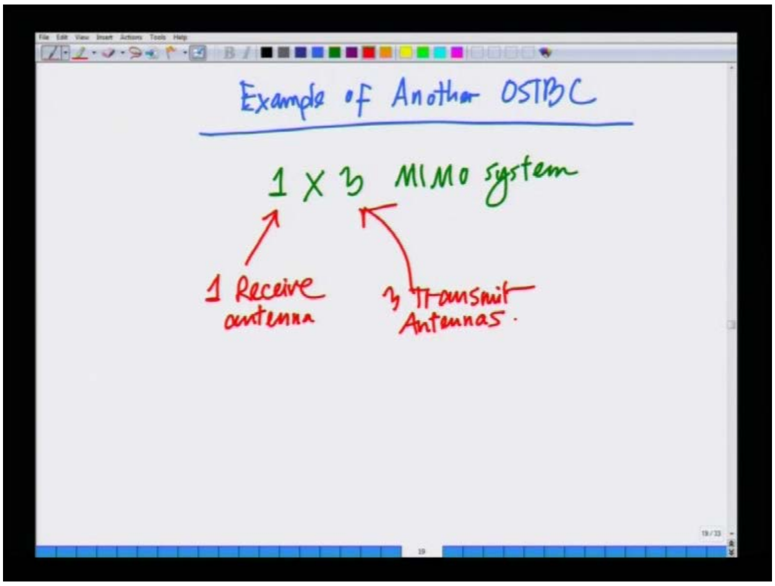

In fact there are other orthogonal space time block codes. So we will see one example of another orthogonal space time block code, an example of O S T or an example of another.

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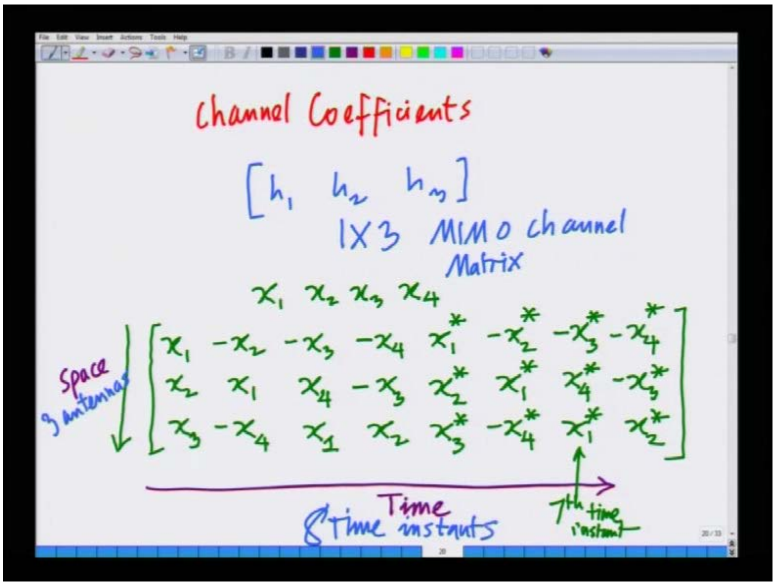

So we will see another example of an orthogonal space time block code, this is for a 1 cross 3 MIMO, this is for a 1 cross 3 system which means 1 receive antenna and 3 transmit antenna. So this is for 1 receive antenna and 3 transmit. So this is for 1 receive antenna and 3 transmit antennas. So in this 1 cross 3 system three is 1 receive antenna, 3 transmit antennas, the channel coefficients or the in fact the channel matrix can be represented as h 1 h 2 h 3, h 1 is the coefficient between the first transmit antenna and receive antenna, h 2 is the coefficient between second transmit antenna and receive antenna, h 3 is the coefficient between third transmit antenna and the receive antenna. So this is h 1 h 2 h 3 this is the 1 cross 3 channel matrix or 1 cross 3 MIMO channel. Strictly speaking this is a MISO channel that is multiple input single output channel but, in general we can call this as a MIMO 1 cross 3 MIMO system.

Now the space time block code structure I will write down the space time block code structure over here, it transmits each instants, each time instant it obviously transmit 3 symbols because there are 3 transmit antennas in the first time instant it transmits x 1 x 2 x 3. So we will use the similar structure that this is space and this is time and this is a block in space time hence, this is a space time block code, in additional if it is orthogonal then it is a orthogonal space time block code. Here however we are we are also concerned orthogonal space time block codes since it is an OSTBC.

So first time instant I transmit x 1 x 2 x 3 that is x 1 from transmit antenna one, x 2 from transmit antenna two, x 3 from transmit antenna three. In the second time instant we transmit minus x 2 x 1 minus x 4 in fact there are four symbols in this block code x 1 x 2 x 3 x 4. So we are transmitting x 1 x 2 x 3, x 1 in the second time instant we transmit minus x 2 from transmit antenna one, x 1 from transmit antenna two, minus x 4 from transmit antenna three and I will give the rest of the block minus x 3 x 4 minus x 3 x 4 x 1 minus x 4 minus x 3 x 2 x 1 conjugate x 2 conjugate x 3 conjugate minus x 2 conjugate x 1 conjugate minus x 4 conjugate minus x 3 conjugate x 4 conjugate x 1 conjugate.

That is I am transmitting minus x 3 that is in time instant 7 remember, this is the 7'th time instant. In the 7'th time instant I am transmitting minus x 3 conjugate from transmit antenna one, x 4 conjugate from transmit antenna two and x 1 conjugate from transmit antenna three and in the final instant I will transmit minus x 4 conjugate from transmit antenna one, minus x 3 conjugate from transmit antenna two, x 2 conjugate from transmit antenna three. This is space which comprises of three transmit antennas, this is time which comprises of a total of 8 time which comprises of. So this is 3 antennas 8 time instants 4 symbols over 8 time instants.

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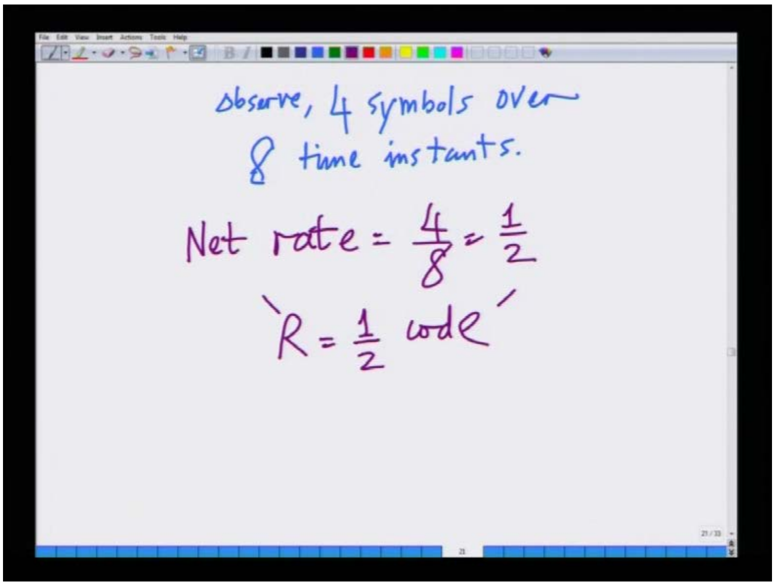

So first observe 4 symbols over 8 time instants. Hence, rate or net transmission rate, net rate equals 4 by 8 equals half. Hence, this is a rate half transmission code. This code for 1 cross 3

MIMO systems or 1 receive antenna 3 transmit antennas in fact transmits four symbols x 1 x 2 x 3 x 4 in 8 time instances. So the net rate is 4 symbols, in 8 time instants which is 4 over 8, which is half. Since this is a R equals half code. So this is a rate half code. So this is an R equals half code.

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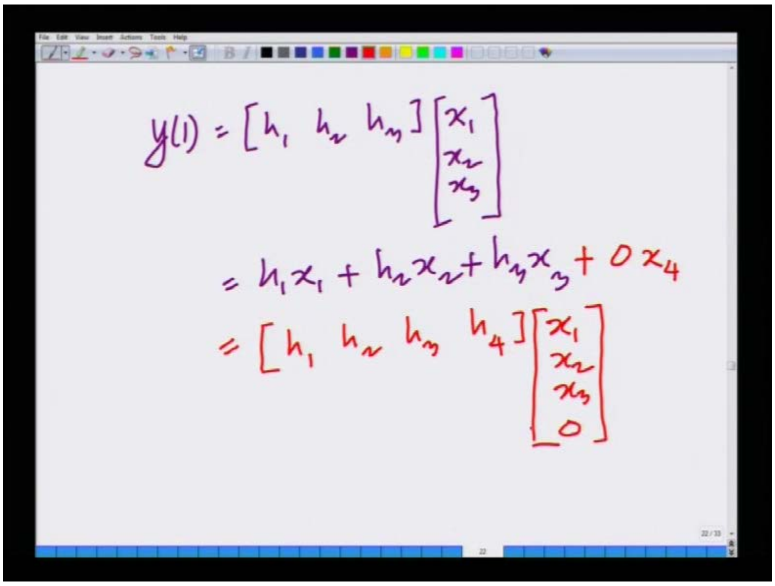

Now what I am going to do is I am going to first illustrate how this can be written for instance, this can be let us consider the first receive symbol corresponding to this code y 1 equals h 1 h 2 h 3 into x 1 x 2 x 3 alright. There are three, these are the three transmit symbols, these are the three antennas in fact I can write this as this is, h 1 x 1 plus h 2 x 2 plus h 3 x 3 plus I can write this as an additional plus 0 times x 4. Hence, I can write this as h 1 h 2 h 3 h 4 x 1 x 2 x 3 and a 0. Hence, I can write this an h 1 h 2 h 3 h 4 x 1 x 2 x 3 and then a 0 at the end.

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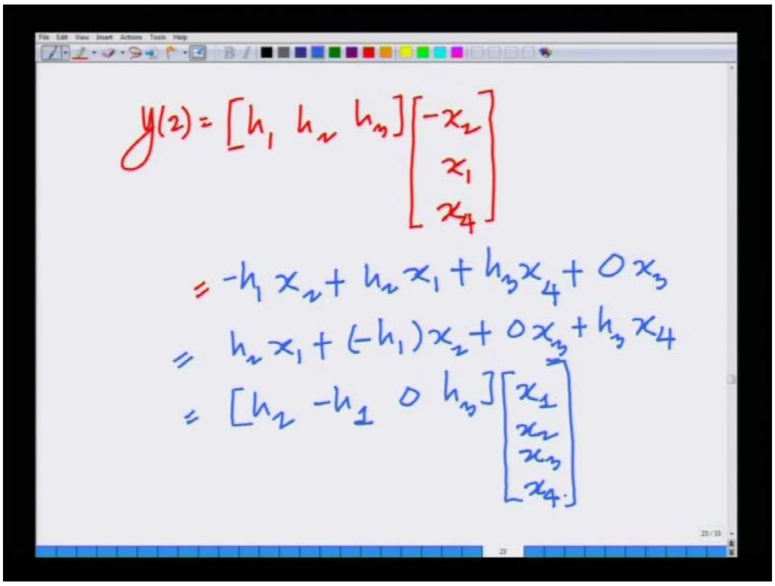

Similarly, let us look at the second transmission, the second transmission y 2 equals h 1 h 2 h 3 into remember in the second instant, it is minus x 2 transmitted from transmit antenna one, x 1 transmitted from transmit antenna two and x 4 transmitted from transmit antenna three. Hence, this is nothing but, minus h 1 x 2 plus h 2 x 1 plus h 3 x 4 plus 0 into x 3. I can write this I can rearrange this addition as h 2 x 1 plus minus h 1 into to x 2 plus 0 into x 3 plus h 3 into x 4 and now I can write this in terms of after rearranging these terms corresponding to the second transmission time instant across the three antennas I can rewrite this in vector form as h 2 minus h 1 0 h 3 x 1 x 2 x 3 x 4. I can rewrite this as x 1 x 2 x 3 x 4.

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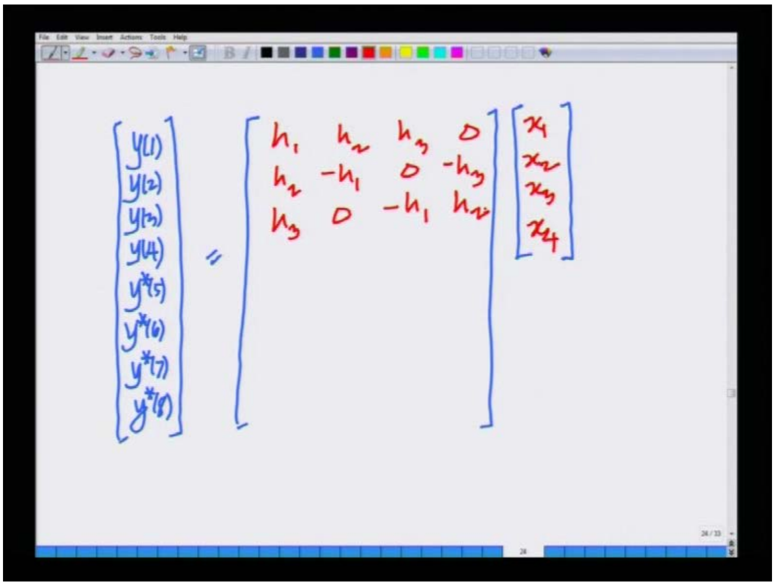

So proceeding similarly, I will not go through each and every simplification. I am going to directly write how the final system looks like the, in the final system I stack y 1 y 2 y 3 y 4 and y 5 conjugate y 6 conjugate y 7 conjugate y 8 conjugate. I can stack this and I can write this equivalent matrix as follows on the right hand side I have x 1 x 2 x 3 x 4 and this channel matrix is the first row is a h 1 h 2 h 3 0. That is what we had derived earlier. The second row is h 2 minus h 1 0 minus h 3, third row is h 3 0 minus h 1 h 2. I am sorry there should be a minus h 3 here because this is a minus x 4, this is a minus h 3, this is a minus h 3 this is a minus h 3 0 minus h 1 h 2.

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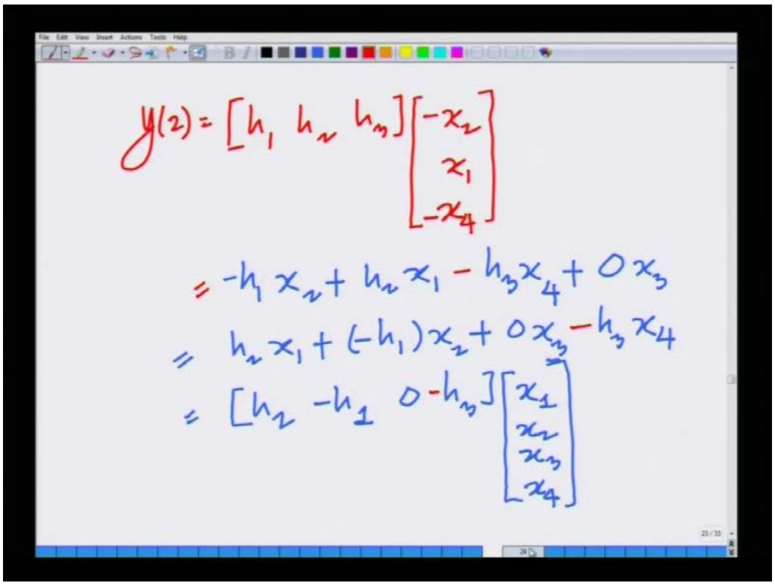

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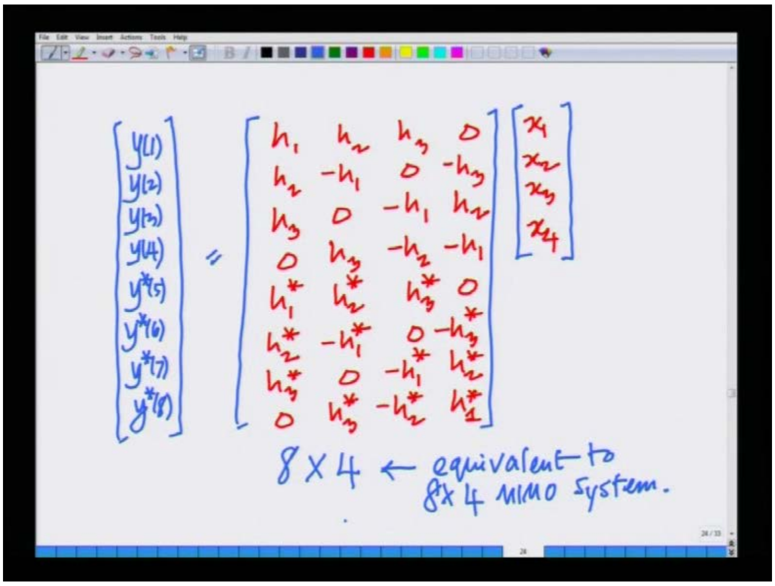

0 h 3 minus h 2 minus h 1 h 1 conjugate h 2 conjugate h 3 conjugate 0 h 2 conjugate minus h 1 conjugate 0 minus h 3 conjugate h 3 conjugate 0 minus h 1 conjugate h 2 conjugate 0 h 3 conjugate minus h 2 conjugate h 1 conjugate. So this is the final block equivalent block matrix. You can look at this. This is of dimension 8 cross 4 and that is what we expect because this is 8 time instances, y 1 y 2 y 3 y 4 y 6 up to y 8 and 4 symbols which is x 1 x 2 x 3 x 4. So this is equivalent to an 8 cross 4.

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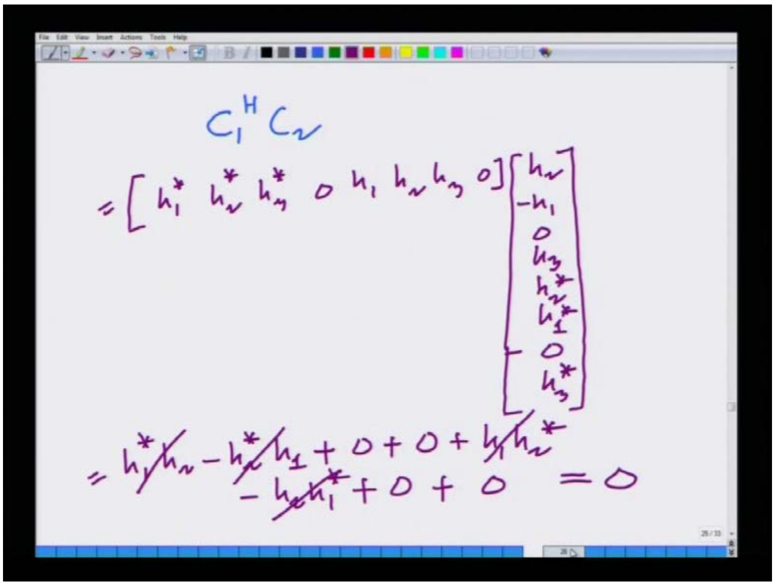

Hence this is equivalent to this space time block code, is equivalent to an 8 cross 4 MIMO system, which is 8 transmit time instants and 4 transmitted symbols that is, x 1 x 2 x 3 x 4 and this is a rate half code. Now you can see again I will illustrate for one case that the columns are orthogonal. Let us look at C 1 Hermitian C 2. Let us look at consider C 1 Hermitian C 2 that is nothing but, h 1 conjugate h 2 conjugate h 3 conjugate 0 h 1 h 2 h 3 0 into h 2 minus h 1 0 h 3 h 2 conjugate h 1 conjugate 0 h 3 conjugate and this is nothing but, h 1 conjugate h 2 minus h 2 conjugate h 1 plus 0 plus 0 plus h 1 h 2 conjugate minus h 2 h 1 conjugate plus 0 plus 0. You see that h 1 conjugate h 2 cancels with h 1 h 1 minus h 1 conjugate h 2 h 2 conjugate h 1 cancels with minus h 2 conjugate h 1 cancels with h 2 conjugate h 1 hence this is net 0.

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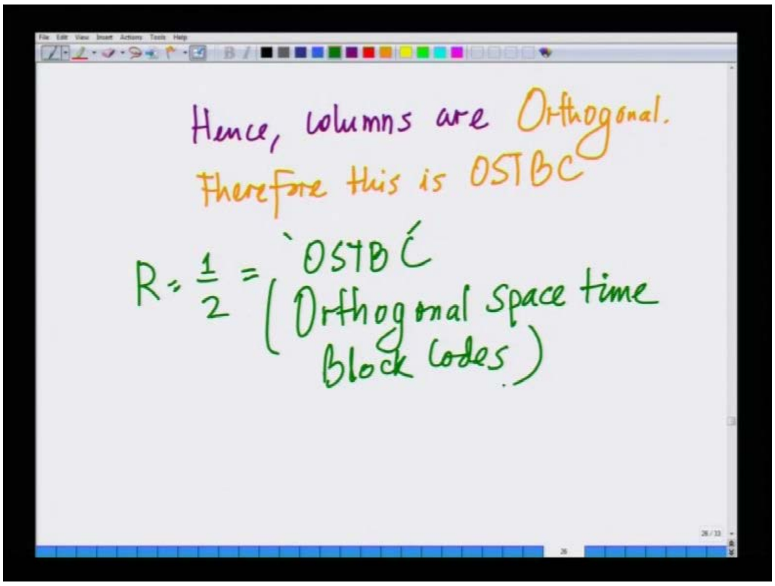

Hence, columns are therefore, this is an OSTBC therefore, this is an OSTBC that is an orthogonal space time block code. In fact this is rate equals half because remember we said we are transmitting 4 symbols in 8 transmit time means, this is rate half OSTBC. Where OSTBC stands for orthogonal and this of course, can be used to employ to extract third order diversity that is that is to achieve third order diversity corresponding to h 1 h 2 h 3 remember there are only three coefficients, this can successfully employ to achieve third order diversity for at the receiver.

And of course, and the main advantage is you can achieve third order diversity without knowledge of the channel coefficients at the transmitter alright. So this is another example of an orthogonal space time block code. So this is an example of OSTBC with that we come to the conclusion of the section on OSTBC that is orthogonal space time block codes. Next I want to go into one of the topics that we left out earlier which is the non-linear MIMO receivers remember, we said we are going to tackle them later. So we are going to now look at non-linear MIMO receivers because that needed some background with respect to the MIMO channel decomposition and so on.

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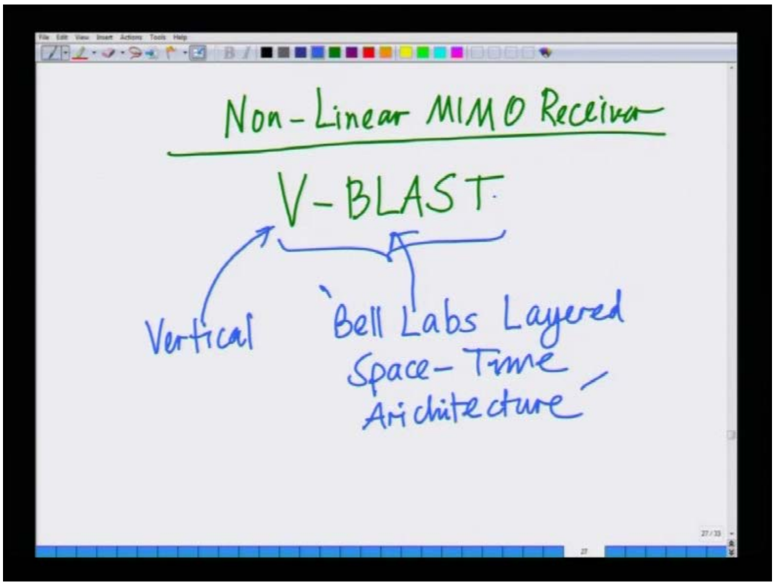

So now we will look at one example of non-linear, this is an example of a non-linear MIMO receiver. In fact what we were we are going to do is we are going to look at what is known as V-blast, V stands for vertical and blast stands for Bell labs layered Bell labs layered space time architecture. So we are going to consider the V-blast technique which where, V stands for vertical, b blast stands for bell labs layered space time architecture.

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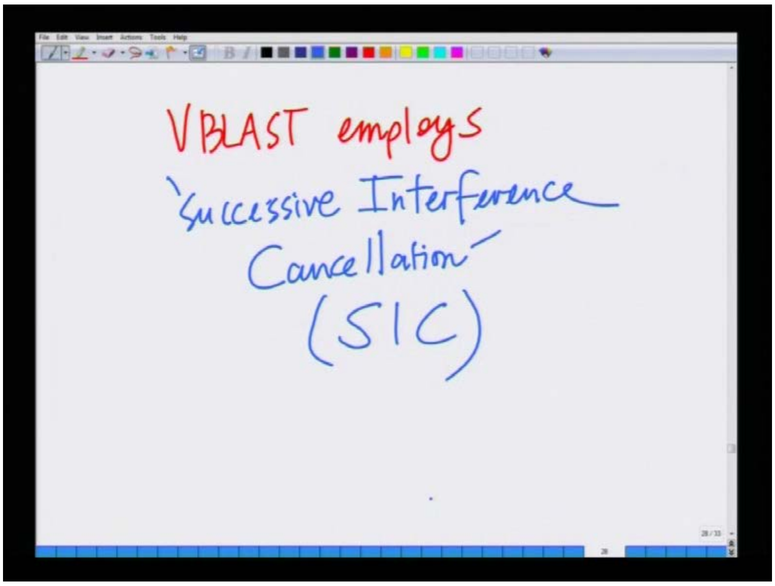

So this is a non-linear receiver, in fact it employs successive interference cancellation. The technique it employs V-blast, in general V-blast employs; this employs successive interference cancellation, which is also termed as abbreviated as SIC. That is successive interference cancellation and the impact of each estimated symbol is cancelled from the received symbol vector.

So what what what this roughly means, is in successive interference cancellation estimate one symbol in the vector x 1 x 2 x 3 x 4. Let us say we estimate x 1, then we remove the impact of x 1 from the receive vector y and then we decode the rest of the symbols. Similarly, after decoding every symbol we progressively remove the effect of that on the received symbol vector and go on to decode the other received symbol, this is successive interference cancellation. So because of lack of time I will have to end this lecture here and we will start again the next lecture at this point with a discussion of a more thorough discussion of V-blast which is vertical bell labs layered space time, non-linear receiver architecture for multiple input, multiple output, wireless communication systems.

Thank you very much.