MR. TAYLOR: This gentleman here has a question. Let's take one more.

UNIDENTIFIED SPEAKER: Mine is not a question. I just thought that maybe he might inform us as to how he set the CW signal on channel and then superimposed the other on the test?

MR. SCHLAFLY: As to how that was done?

UNIDENTIFIED SPEAKER: Just to tell us how you set this up?

MR. SCHLAFLY: There were 12 input channels and there was a CW generator. The input channel levels were set through those modulators and the CW level was set at the same level as the carriers that we had from off-the-air signal.

UNIDENTIFIED SPEAKER: But, when you set the CW signal in this test you showed, do you kill the other information on that channel?

MR. SCHLAFLY: Yes, sir. There was only the pure CW signal on that channel and it beat against the various signals of the television channels that were superimposed, mixed at the input to the amplifier. (Applause)

MR. TAYLOR: Again I want to thank Mr. Schlafly very, very much for coordinating this study on behalf of the Ad Hoc Standards Committee. And, again, I want to express the tremendous cooperation that has been given to this project by a number of manufacturers. We'll delay just a moment or two while the gear is removed to make possible some other visual aids.

I might say that many of the papers you will hear today are available in printed form and will be available on this table against the wall.

Our next speaker is Dr. Jacob Shekel of the Spencer-Kennedy Laboratory. You have his sketch here showing his background and I will not take further time to introduce him. Dr. Jacob Shekel. (Applause)

DR. JACOB SHEKEL: My talk will concern noise and cross-modulation from a few points of view. We all realize that noise and cross-modulation are the factors that ultimately limit the length of the system or the number of amplifiers that can be cascaded. But, I'm not sure that everybody here knows exactly how to estimate how many of the amplifiers can be cascaded and when that limit is reached; and how to do this before the system is built and before you find it out in effect. I want to separate the problem into three parts: First, how do we specify or measure or estimate the noise and cross-modulation of a single amplifier? Then, knowing that, how do we estimate the accumulation of noise and cross-modulation along the trunk line and distribution amplifiers? And, the third question, where do we stop? How far do we let it accumulate before we say this is as far as we go, because we cannot degrade the picture any further?

I am not going to discuss the third question. I am not going to give any numerical values on what should be the final noise or the final cross-modulation, because that is really up to the Standards Committee to set up. I don't think there is yet any complete agreement between the manufacturers or between the system users on the ultimate degradation that can be allowed. But I will describe what I hope is a very simple way of how to figure out from the specification of a single amplifier what the noise and cross-modulation of the total system are expected to be at the furthest point.

A simple way to estimate the noise at the end of the system, and one that I know is used quite extensively by system operators, is a simple measurement with a field-strength-meter. You measure the level of a certain channel at the furthest point of the line. Then you turn off the channel at the head-end and see what measurement you can read on the field-strength-meter. This measurement is due only to noise accumulated all along the system. You take the ratio of these two measurements--that is, the difference of the db readings--and this is what is called carrier-to-noise ratio in decibels.

Now, since this is such a simple method to measure the carrier-to-noise ratio of the system, we can also define and specify tne amplifier the same way. Suppose we take a single amplifier of the kind that we're using in the trunk line, and connect the field-strength-meter at its output, terminate the input and read the meter. Let's take as an example that the field-strength-meter reads at a certain channel --28 dbmv. Then suppose that this amplifier is specified to be used at an output level of +33 dbmv. By subtracting the two numbers, remembering that one of them is negative, the carrier-to-noise ratio of a single amplifier appears to be the difference between 33 and minus 28, which is 61 decibels. This, I think, is the simplest way to measure and to estimate the carrier-to-noise ratio of a single amplifier, a measurement that every operator can do right in his own office or in the field.

Knowing the carrier-to-noise ratio of a single amplifier, what can I expect to be the carrier-to-noise ratio when I cascade any number of them? Or, an alternative question, how many can I cascade if I want the carrier-to-noise ratio to be at least (let's say) 45 db?

Now, here we have to go a little into a table of decibels. I want to show a very simple method that every one of us can follow to make up his own table of decibels without reference to any handbook or any slide rules. I think it's a very handy thing to know.

First, we have to realize that the noise is a random waveform, and if you take the noise contributions of the various amplifiers they are not coherent. If you project them on a scope there will be no similarities between the noise waveforms of the various amplifiers. When such waveforms are added, the power of the total wave is equal to the sum of the powers of the various contributions. That means that a noise of two amplifiers will be 3 db higher than the noise of a single amplifier, and the noise in a trunk of 10 amplifiers will be 10 db higher than that of a single amplifier.

These are the only two numbers that we have to remember, that "twice" is 3 db and "10 times" is 10 db. I am going to write down the column of dbs from 0 to 10. We know that 0 db is a ratio of 1, and every time we add 3 db we double the ratio. Twice is the same as 3 db. So 3 db would be 2, and 6 db is 4, and 9 db is 8, and 12 db is 16, 15 db is 32 and 18 db is 64. Now, we go the other way. 10db is 10 times. Going backwards, 3 db below that, 7 db would be 5 times, and 3 db below that, 4 db, would be 2.5, and 3 db below that would be 1.25. To complete the table we now go sideways, multiplying and dividing by 10.

DB	NUMBER	DB	NUMBER
0	1	10	10
1	1.25	11	12.5
2	1.6	12	16
3	2	13	20
4	2.5	14	25
5	3.2	15	32
6	4	16	40
7	5	17	50
8	6.4	18	64
9	8	19	80
10	10	20	100

For each 3 db step

Multiply by 2 ↓ ↑ Divide by 2

Multiply by 10 →

Divide by 10 ←

Fig. 1

So, now we know how noise of various amplifiers will combine, or how the carrier-to-noise ratio will change along the line. In our example I have used the carrier-to-noise ratio of a single amplifier at 61 db. If I had two amplifiers they will be 3 db worse, or 58 db; and with 10 amplifiers, it will be 51 db.

Now, let's take the following question: If I start with a 61 db carrier-to-noise ratio of a single amplifier, how many can I cascade before I reach 45 db? The difference between 61 and 45 is 16. Going to the table, 16 means 40 amplifiers. So, 40 amplifiers of that type, operated at that level, will give a carrier-to-noise ration of 45 db. I can't say whether that is acceptable or not, but at least the system operator can go to the end of the system and measure the carrier-to-noise ratio, and if the reading is far from 45 db, then he knows right away that something must be wrong.

This is as far as we can estimate the carrier-to-noise ratio of a single amplifier and of a line with cascaded amplifiers. And, you will have noticed that I am trying here to specify the noise of the amplifier not by its noise figure, which is a certain measurement referred to the input, but by its noise output. First of all it is easier to estimate the output C/N ratio, and also it's a figure which is much easier to measure right in the field.

The second limitation on the system performance is the matter of cross-modulation. Now, of course, I'm not sure if we all know, after the previous demonstration, what exactly cross-modulation is. Maybe we know much more than we knew an hour ago. But, for the purpose of my talk it suffices that we can put a number to it. We say that an amplifier operated at a certain level with a given number of channels will have a certain amount of cross-modulation.

First of all, it is important that both the level and the number of carriers be specified, because the amount of cross-modulation changes with those two numbers, as it was demonstrated before. Also, the number which specified the cross-modulation can be given in two ways: It can be given in negative decibels (or "db down"), or it can be given as a percentage modulation. The meaning of the latter is that if we start with a CW carrier as our test signal, the modulation imposed by the other carriers will be a certain percentage.

The two specifications are equivalent to each other and there is a very simple way of passing from one to the other.

Let's look first at just the middle line of the nomogram on page 165, the one that is marked "cross-modulation". Here you see two scales, one in decibels and the other in percentage. For example, minus 40 db corresponds to 1%, minus 60 to .10% and minus 72 corresponds to .025%.

Now I would like to suggest that specifications be given in percentage rather than db, because then the way that cross-modulation accumulates along the trunk is very simply computed: You just multiply this number by the number of amplifiers. Let's take as an example that a trunk amplifier is specified to have .008% cross-modulation when operated at an output level of +33 dbmv with 12 channels. (How to get this number in the first place will be shown later. It could be the number given directly by the manufacturer, or it may have been computed from an equivalent number given by the manufacturer.)

The cross-modulation is really a superposition of the modulation of other channels onto the channel we are watching. And as we go along the line, all the contributions of all the amplifiers just add up in phase on top of each other, because all the channels progress along the line at the same speed. If we have a cross-modulation of .008% for one amplifier, we will have a cross-mod of .016% for 2 amplifiers and .024% for 3 amplifiers. Suppose we have 30 trunk amplifiers, and all of them operated at the same level, the total cross-modulation will be .008 times 30, which is .24%.

Now, this is only the trunk. We also add cross-modulation in a bridging amplifier, distribution amplifiers, line extension amplifiers. (Incidentally, in these amplifiers, since we try to operate them at the highest level possible, we do have cross-modulation, but we have almost no effect on the noise. That's why I have disregarded it in the first part of my talk).

We have .24% accumulated along the trunk line. Suppose that now we start from here into a distribution amplifier, and let's take again as an example that it is specified to have .1% cross-modulation at +58 dbmv for 12-channel operation. If we operate it at this level, it will add .1% cross-mod. Again all the channels come to this amplifier at the same time, all together, so on top of the .24% from the trunk line we have to add .1% of the distribution amplifier and we end up with .34%.

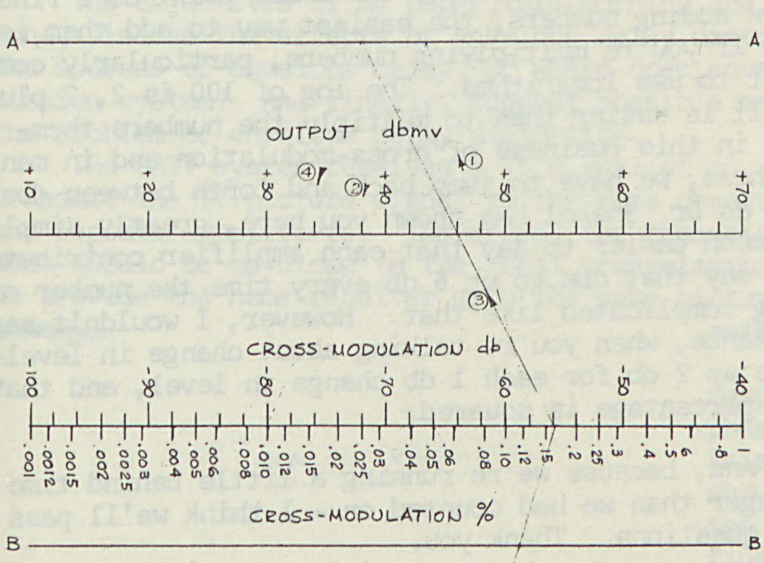
If we have no further amplifiers in the line, we can expect the customer to have a cross-mod of .34%. Suppose that a customer is further along the line, where we have another line-extension amplifier. All we have to do again is to add the cross-modulation contributed by that amplifier. And, thus by a simple process of addition of the contributions of various amplifiers we can very easily estimate the cross-modulation of the pictures at the customer tap.

There is some difference between noise and cross-mod measurements, because the noise can easily be measured at the customer tap and you can compare this to the computed results; whereas, the cross-mod measurement is a little more complicated and the equipment is usually not such that can be taken to the customers' house or carried around in a truck. I hope that within a year or so maybe some of the manufacturers will come up with small kits to measure cross-modulation, when the Standard Committee will have decided on a method that is satisfactory to everybody.

Now, the only thing that remains in this method of estimating noise and ss-mod is how to find the cross-modulation of a single amplifier. In noise, it was simple. We just take an amplifier and measure it. We disregard the manufacturer's specs; we can check it every time.

On cross-mod we have to start from one number given by the manufacturer; and various manufacturers have various ways of specifying. For example, some manufacturers specify the level at which the cross-modulation for a number of channels is 57 db, while at least one other manufacturer specifies the level at which the cross-modulation is .05% when only two carriers are used in the test.

NOMOGRAM FOR THIRD-ORDER CROSS-MODULATION



The nomogram shows a way of comparing these various specifications; and also a method to estimate what the cross-mod would be at the level that you actually use in the amplifier.

There are three scales on this nomogram: The middle scale is the cross-modulation that we discussed before. The upper scale is the output of the amplifier in dbmv, and the lower scale is the number of carriers used. This scale is really in two parts and we can use either of them, whichever is more convenient.

For a first example I'll start with an amplifier specified at .05% two carriers at +46 dbmv, and we want to know what would be the cross-modulation if you operated 12 carriers at +33 dbmv. First, we use the bottom part of the nomogram to find what is the effect of number of carriers. (Here I want to point out that the assumption on this nomogram is that the cross-modulation from various carriers will add incoherently. If we have many carriers that are on the same network that produce coherent sync pulses, the addition will be more severe than it is here.)

So, we join the point of "2 carriers," and .05% cross-modulation, find the intersection with line B, and then connect the "12-carrier" point through that intersection point up to the cross-modulation scale. This shows something around .16% (we don't really have to estimate this point exactly because this is only a partial answer).

Now, we go to the upper part of the nomogram and see what effect the level will have. We have now changed the number of carriers from 2 to 12. We take that intermediate point (which is roughly .16%), correct it to the +46 dbmv and go up to line A. From that point we come down to the +3? dbmv point and we end up on the cross-mod scale at .008%.

To summarize, I've used the bottom part to see the effect of number of carriers at the same output level; and the upper part for the effect of the output level at a constant number of carriers.

As a second example, suppose the amplifier is specified as having -57 db cross-mod at the level of +48 dbmv for 12 carriers. Here we don't have to change the number of carriers, and all we have to work with is the upper part of the nomogram. We connect the point at -57 db to the +48 dbmv, go up to line A. Now, suppose we are using the amplifier at a level of +37 dbmv, so we connect that point from scale A through the +37 and come up to .010% cross-modulation. This is the starting point for the computation of the trunk line.

Well, this is really all I wanted to show. How we estimate, or how we read the specification, or how we measure noise and cross-modulation with a single amplifier at the level we are going to work it, how the noise and cross-mod accumulate along the line and what we can expect as the final noise and cross-mod at the end of the line.

Now, are there any questions?

MR. KEN SIMONS: This really isn't a question. I'm cheating. I'm going to say two words. First, I want to thank Dr. Shekel for a very clear presentation of some facts that are long overdue in this industry. And, only one small point do I find that I would try to add. If you're adding numbers, the easiest way to add them is to add them, 100 plus 100 is 200. If you're multiplying numbers, particularly complex numbers, it's often convenient to use logarithms. The log of 100 is 2, 2 plus 2 is 4, 10 to the 4th is 10,000. It is easier than to multiply the numbers themselves. In the same way I believe in this business of cross-modulation and in many other facets of our community business, we have to jump back and forth between dbs and percent, and I believe we can, as Dr. Shekel has shown you here, greatly simplify the relationships involved. It's much easier to say that each amplifier contributed .1% cross-modulation than it is to say that dbs go up 6 db every time the number of amplifiers is doubled, or something complicated like that. However, I wouldn't say this worked all the time. For instance, when you're talking about change in levels, the amount of cross-modulation goes up 2 db for each 1 db change in level, and that's easier to say than to say that the percentage is squared.

MR. TAYLOR: Thank you, Ken. And, because we're running a little behind time - our demonstration took a little longer than we had counted on - I think we'll pass onto another paper without further questions. Thank you.

DR. SHEKEL: May I just give a not-answer to the not-question. I just want to defend in a couple of words the method of percentage, although as I say they are both equivalent and you can easily pass from one to another. First of all, it seems to me that percentage is easier when you have to add the contributions of various types of amplifiers. The cross-modulation of one is multiplied by the number of amplifiers in the trunk; and when you add the distribution amplifier, it is much easier using percentages.

As far as seeing the effect of output level on cross-modulation when it is in percent, one way would be using the nomogram, and the second way would be using the same table of dbs that I just invented 10 minutes ago. Because, you will check that if you