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Considerations regarding 10MHz external reference clocks: Sine/Square wave; Impedance; Cabling; Filters.

By John R. Swenson

Introduction

Recently there has been a lot of talk about using 10MHz external reference clocks with the **UpTone Audio EtherREGEN** network switch. Namely, there is confusion about what waveform is best, what impedance to use, what type of cable to use, and what numbers to look at in the manufacturers' specification sheets. This paper will attempt to explain some of this, generally and in lay terms, and how these factors interact with each other. This is not a review of or recommendation of specific hardware. The following information is somewhat general—the goal being to help you better understand how different aspects of a clock determine what to look for. The aim is to get a clock with the lowest phase noise to the circuits being clocked. Any of these variations will most likely work. If your EtherREGEN is not working with an external clock, it is not due to one of these issues. This is all about getting the best technical (and sonic) performance.

Noise Types

First off we have to understand two different types of noise—AM and PM—and their characteristics:

- AM stands for *Amplitude Modulation*, which is what most people mean when they talk about "noise," and is a variation in the amplitude of a signal. The infamous "tape hiss" is AM noise.
- PM stands for *Phase Modulation*, which is phase noise. This has to do with timing (jitter), not amplitude. (We'll not go into detail here on exactly what phase noise is. That gets rather complicated and has been covered elsewhere.)

  Suffice it to say that the phase noise of clocks—and its propagation through chip and interfaces—matters a great deal in digital audio. AM only matters because under some circumstances AM can become PM. On an oscilloscope screen, AM is vertical, PM is horizontal.

AM to PM

It is possible for AM noise to get converted into PM noise. This is why things get a little complicated with clocks, so it is important to understand the process which adds PM to the existing PM of a clock signal.

We will start with how this works for a sine wave. A "clean" signal displayed on a scope will show a standard "sine wave" smoothly going up and down, with a very thin line. As AM gets added, the line gets "fuzzy." This is showing the amplitude added to our "clean" signal. In a clock receiver which converts the sine wave into a square wave, there is a threshold voltage. When the signal is above the threshold, the output is high; when the signal is below the threshold, the output is low. With a perfectly clean input signal, the time between these changes would be always the same. BUT with the addition of the AM, the signal might reach the threshold a little earlier or a little later, thus adding variation to the timing—resulting in PM (phase modulation).

How large that time variation is depends upon the slope of the signal. A signal that is slowly rising or falling will produce a much greater time difference (higher PM) than a rapidly moving signal (lower PM). The slope of a sine wave is much lower than the slope of a square wave. An ideal square wave doesn't have a slope; rather it has instantaneous "edges." But in real life that can't happen, as there is always some slope, but it can be very steep (very rapid rise).

So let's look at what happens in the AM to PM conversion with a sine wave or a square wave. With a sine wave, the low slope means the time variation is large. But for the same AM amount a square wave's time variation will be MUCH less. In other words, **an input receiver is much more sensitive to AM on a sine wave than with a square wave.**

An interesting aspect of a receiver is that this sensitivity can be different from one receiver to another. The primary difference is due to bandwidth. Since the AM on a signal is usually very broadband (contains lots of different frequencies), filtering out the frequencies that are not the clock frequency will result in much less AM. This can dramatically decrease the sensitivity to sine wave AM.

The clock receiver of the EtherREGEN is inside the clock synthesizer we use and it is designed to handle a very broad range of input clock frequencies (we program it for 10MHz—or 25.0MHz if just using the internal XO as reference). That makes this input very sensitive to AM noise. Hence sine waves need to have VERY low AM in order to produce low phase noise on the output.

Impedance

Impedance matching MAY have a very significant impact on AM-to-PM conversion. Square waves can be severely distorted by impedance mismatches, but sine waves are barely affected by them. Square wave distortions may significantly affect the sensitivity of the AM to PM conversion (higher PM if a significant impedance mismatch exists).

Impedance mismatches can exist INSIDE the clock box, with connectors and cable, and inside the receiver. IF you have a square wave clock, you need to make sure these match; if you have a sine wave it doesn't much matter.

Cable types

There are three primary aspects to a cable that come into play with clocks: impedance, shielding, and bandwidth limitations.

You are probably familiar with impedance. For our purposes the choices are 50 ohms or 75 ohms; neither is better or worse, they just have to match. However, a word of warning: there are a LOT of cables that say they are 75 ohms, but have 50 ohm connectors on the ends.

Different cables have different types of shielding: single, double, semi-rigid, etc. Each of these has different shielding properties—single being the worst, and semi-rigid being the best. As you get better shielding, the price of the cable goes up dramatically. If a cable has single shielding, the spec sheet will probably not mention its shielding type. Semi-rigid is essentially copper tubing with a Teflon interior and a conductor down the middle. It has 100% shielding but is difficult to work with. For "jumpers" between boxes next to each other, this is the way to go if you need good shielding.

The next aspect is attenuation with increasing frequency. ALL coax cables exhibit this behavior. The attenuation at 10MHz is always very low, but as the frequency increases the attenuation can get quite high. There are two aspects of the cable that determine this: what the insulation between the center conductor and the shield is made from, and the diameter of the cable.

Teflon, polypropylene, and some silicone rubbers have much lower attenuations with increasing frequencies compared to other less expensive insulations (referred to as "dielectrics" in electronics.)

So why is this important? A square wave is made up of a whole sequence of "harmonics" which make the signal "square." Attenuating these harmonics makes the signal "rounded" which means the edge slope is a lot less, causing the AM to PM conversion to be more sensitive, increasing PM. BUT since a sine wave has no harmonics, this doesn't make ANY difference!

Combinations

Now to the fun part—how all the above interact with each other. First let's talk about the choice between sine and square.

For sine waves, the AM to PM sensitivity is high, BUT they are not sensitive to impedance mismatch or cable attenuation with increasing frequency. Because of the high AM to PM sensitivity, you probably want to use a cable with very good shielding. But that doesn't help any AM noise on the signal to begin with, just what it picks up going from box to box.

For square waves you DO need to make sure you have good impedance matches, but there is nothing you can do if the clock box already has a mismatch. You don't care about cable shielding, but you DO want very small change in attenuation with frequency (usually called a wideband cable).

Note that neither needs both very good shielding or very low attenuation with frequency. Thus getting a cable with both is just wasting money either way.

So which is best? It's really hard to tell. IF the clock box has a very good sine-to-square converter built inside (and there are REALLY good ones if done right, but who knows what is inside a particular box), and the box designer didn't mess up the impedance inside the box, AND you get the right cable (low attenuation with frequency), a square wave will probably give the best results.

A particular sine wave box may be better if the square wave converter gets things wrong, and of course you'll want to use a really well shielded cable. Unfortunately there is no easy way to tell how things are going to be. In one respect sine waves make things easier because it doesn't matter if the designer messed up the impedance matching, but the sine wave may have a lot of AM to begin with.

Just because a clock box says it contains an OCXO with something like -135dBc/Hz at 10Hz offset doesn't mean it will be better than one that says it has -130. IF the -135 one has impedance mismatches inside, or much AM on a sine wave, the result after going through the clock receiver may be worse. OR the -135 one could be designed really, really well and will be spectacular in the clock receiver. It's hard to tell.

Filters

There is another concept that can affect the above advice: Filtering a sine wave signal at the load. If you run a 10MHz sine wave signal through a filter designed to radically attenuate anything that is not 10MHz, you can get rid of most of the AM that might be on that sine wave—either from what was put there in the clock box or what the cable picked up. Such filters exist and they come with BNC connectors on each end.

Recommendations

Taking all the above into consideration, a great way to go is to use a sine wave output and feed that into the appropriate filter plugged into the external clock jack on the EtherREGEN. With this configuration, you don't need a super expensive cable since you don't need either really good shielding OR low attenuation with frequency. It won't matter if the designer messed up the impedance matching inside the box, or even if you use the right impedance cable. The phase noise coming out of the clock box will be pretty much the same getting fed the internal circuits of the EtherREGEN.

One such filter is made by a company called Mini-Circuits. They make hundreds of models of high frequency filters but the desired one for application with a sine wave clock is part number BLP-10.7-75+ or BLP-10.7+. It is a precision low-pass filter, allowing through frequencies from DC up through 11MHz, and providing good attenuation above that range. The difference between the two part numbers mentioned is that one is 75-Ohm and the other is 50-Ohm. But if you have been understood what has been explained in this paper you will know that for this application with a sine wave clock it matters not at all which impedance filter you choose! Whichever one is in stock. (Nor does it matter if your EtherREGEN has the standard 75-Ohm BNC or the available-upon-request 50-Ohm BNC clock input.)

Using this approach will probably work well with anything. Just remember that the best possible result is still going to be using a square wave clock box with a REALLY good sine to square converter, everything being just right inside the box—AND you use a really low-attenuation-with-frequency cable. But truly superior square wave clock boxes and commensurate cables are not cheap! So if you don't know what is inside the box, going with a sine wave clock and the above filter is probably the best way to ensure you are actually getting the low phase noise properties of the oscillator inside the box.