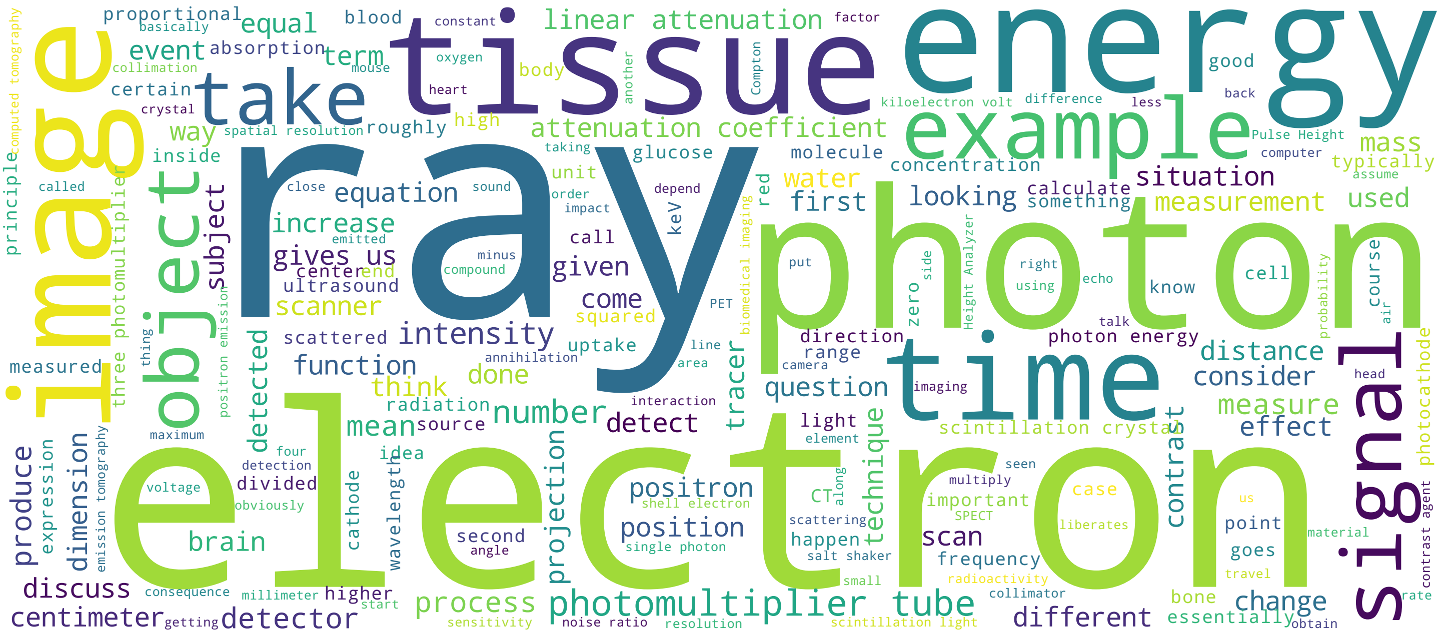
# 5.5 Principle of x-ray detection II: Photomultiplier Tubes

## Fundamentals of Biomedical Imaging

Prof. Rolf Gruetter

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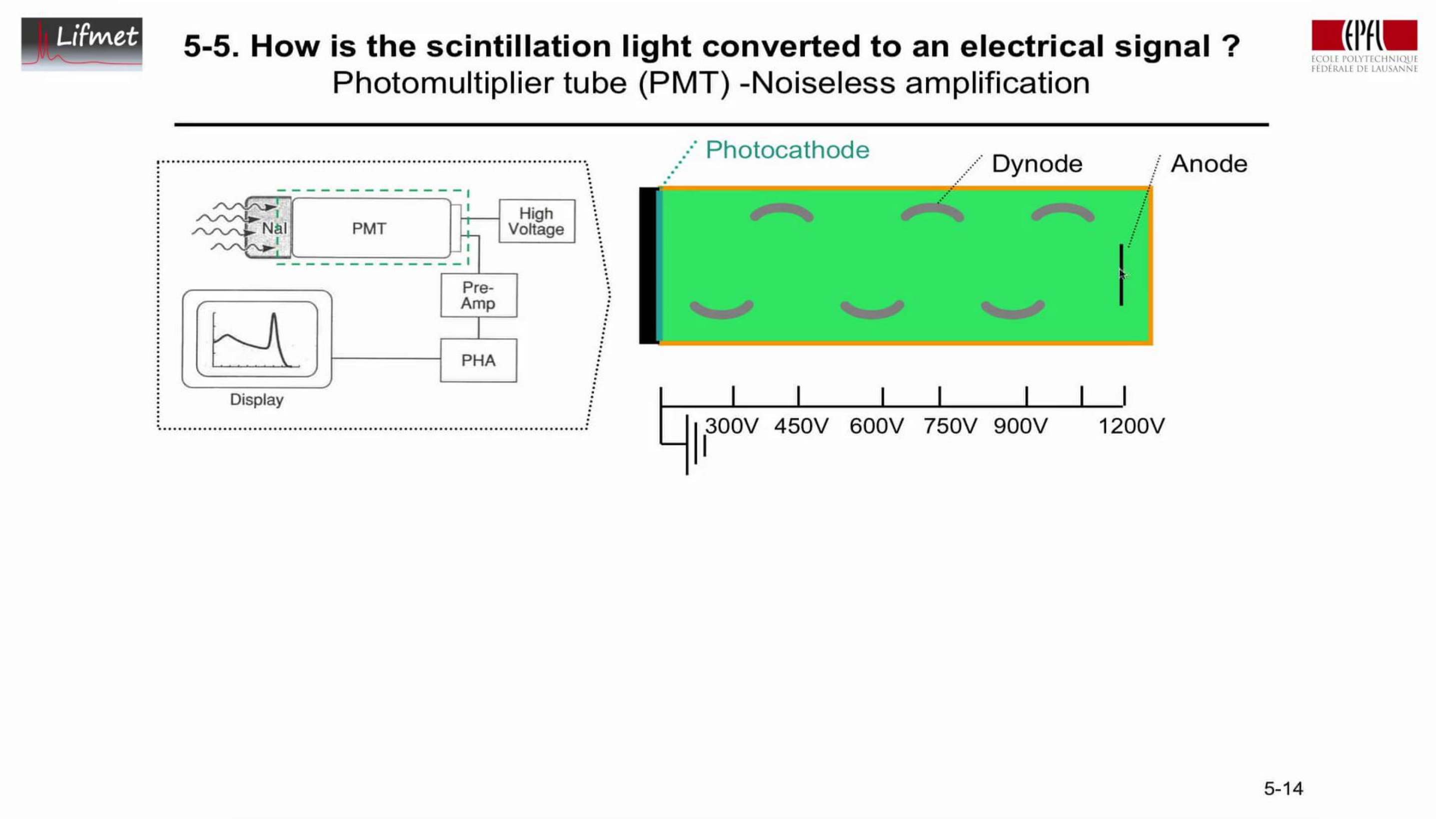



In the process of generating a measurable signal that we can deal with in the camera and/or the computer, we have to get that visible light measured, and the question is, how do we convert the scintillation light to an electrical signal? The process that's being used is that of a photomultiplier tube. It's a bit different from what we use in our CCD cameras, in our cell phones, so we have the scintillation crystal. Here is the example, sodium iodide. That's the whole process. We have the photomultiplier tube here whose produced signal is being amplified. There's a Pulse Height Analyzer. PHA stands for that, and it displays the signal. Now I'll discuss what is inside this photomultiplier tube, what is the process that is going on. First, we have the photocathode, we have the photomultiplier tube in vacuum and there are subsequent anodes and cathodes. These pairs of anodes and cathodes are called *dynodes*, and we have the final anode here, which is where the signal is finally being detected. One applies a voltage, and in this typical example, this goes in increments of 150 Volts, zero, 300, 450, 600, 750, 900, etc. until 1.2 Kilovolts is the voltage that's being applied.

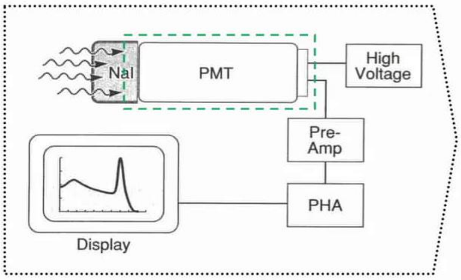
Notes

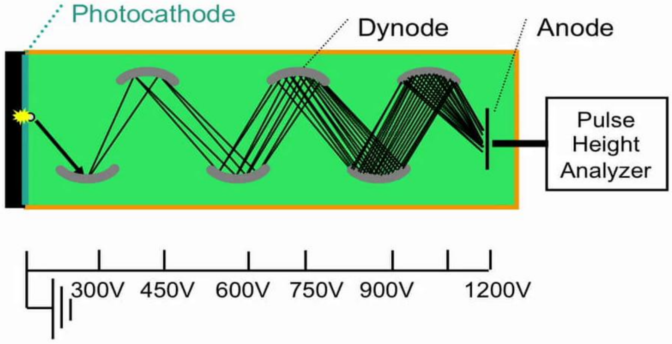
Summary

0m 04s

## 5-5. How is the scintillation light converted to an electrical signal ?

Photomultiplier tube (PMT) -Noiseless amplification



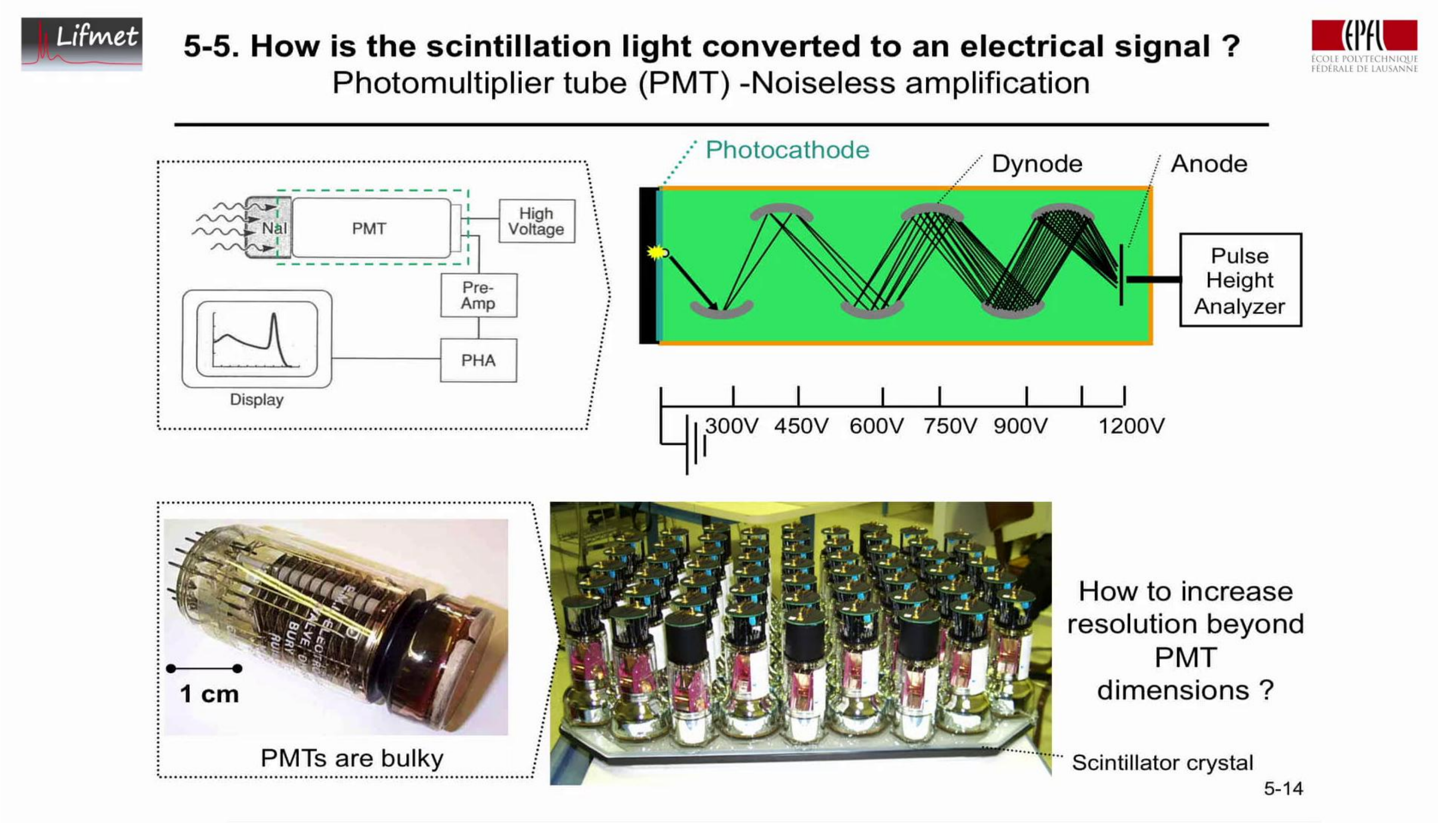

5-14

At the end, a signal is being detected that is sent to the Pulse Height Analyzer. Let's say we have a visible photon that impacts the photocathode. What it does in the photocathode, we won't go into the details here, it liberates one or more electrons. Let's say it liberates one electron. This electron from the cathode is accelerated towards the first anode where it liberates again more electrons. We'll take an example of two, so out of one electron, we have two. At the next point here where it's accelerated towards we have -- again, we'll always assume there's a factor of two. One electron produces two electrons, so now we have four electrons that are right here. We produce, again, with a dynode, from four to eight, and then to 16, and finally to 64 electrons that go to the Pulse Height Analyzer. This process essentially allows us from more or less a single photon here to produce a measurable signal of many electrons that we can measure the change in signal, the electrical signal of those electrons when they arrive to the final anode of the photomultiplier tube. This is actually technology from more than a half century ago. It is providing virtual noiseless amplification of the signal.

Notes

Summary

1m 29s

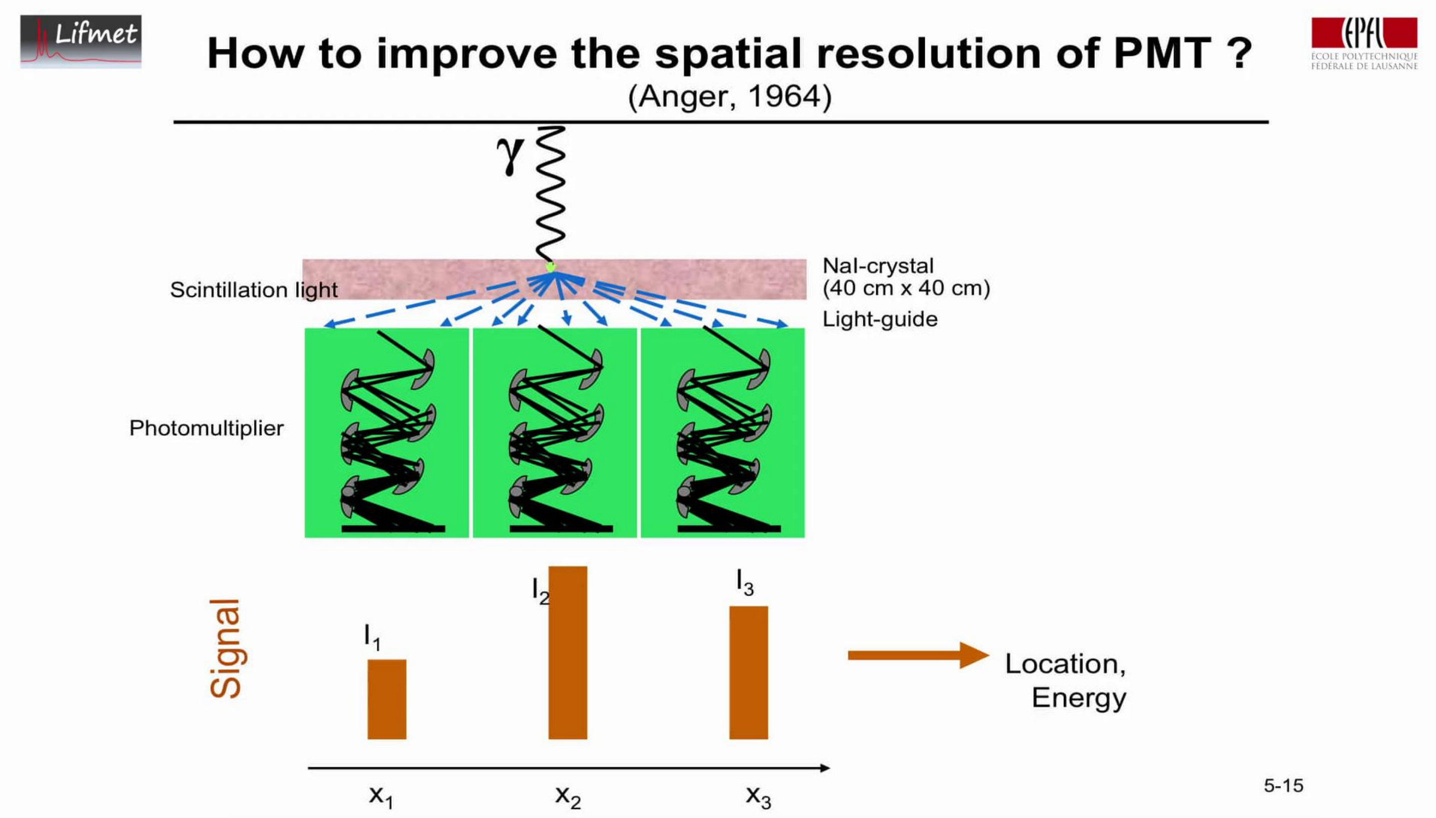



What does a photomultiplier tube look like? Here it is. We have here the photocathode, the subsequent dynodes, and here are the connectors that connect to the instrument. Let's think of what the dimensions of this is and let's give you a scale here. This is roughly a centimeter. These are fairly-- they're almost like the size of a salt shaker. But wait, let's think: we want to have images with a spatial resolution, typically on the order of millimeters, but we have, in the end, the units that detect our signal. They have dimensions on the order of an inch, two centimeters, so salt shaker size. They are bulky, not adapted to the resolution that we would like. To give you an idea what this looks like here, here we have such a detector board. Here is the scintillation crystal. Here's the wave guide, and here are all these photomultiplier tubes. Looks like a happy family of salt shakers, doesn't it? Yes. But now, how do we get high resolution images from this? How can we increase the spatial resolution beyond the physical dimensions of the photomultiplier tube?

Notes

Summary

3m 06s

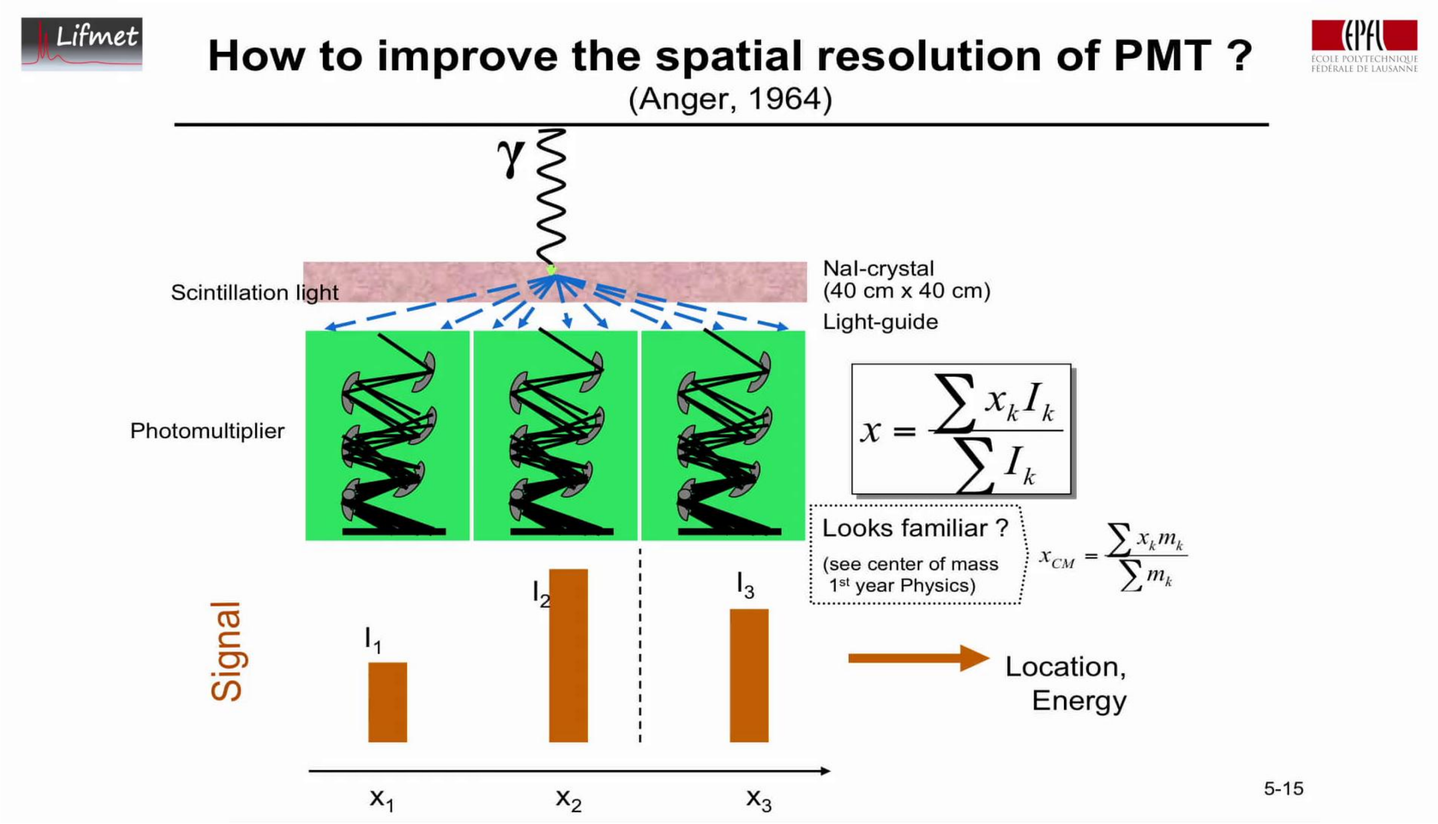



That's the question: how do we improve the spatial resolution of the photomultiplier tube? Let's consider the situation here. We have a sodium iodide crystal of 40 centimeters by 40 centimeters. It's perpendicular to the plane. We have a light gate, and then we have, here we've drawn three photomultiplier tubes. We'll say that the position of these three photomultiplier tubes is X1, X2, and X3. We have an X-ray that interacts with the scintillation crystal, so it produces scintillation light. This scintillation light is detected in this case by all three photomultipliers so they multiply the signal according to the number of scintillation photons that they detect, and therefore, we obtain now from the single photon here, X-ray that has impacted here, that has made the interaction here, we're obtaining in these three photomultipliers three signals. We'll call this Intensity 1, Intentsity 2, and Intensity 3. What we have said is: the number of scintillation photons produced is proportional to the energy of the X-ray so we have energy information. Now, how do we get the position of the X-ray, figure it out?

Notes

Summary

4m 15s




Just from the intensity I1, I2 and I3, if I measure it this way, I can say it's not on center on I2 because this is higher than I1 so somewhere the event with these intensities must have happened here along where we have the dashed line. The precise calculation is done with this equation here. We'll multiply the intensity of each photomultiplier tube with their position and we'll divide it by the total intensity measured. That gives us the precise location of the photomultiplier tube. This is just done for the dimension of X. We don't need to worry about how we do it in two dimensions. Once you flash back to where this equation comes from, I have no doubt that it becomes fairly apparent. Does this equation look in any way familiar? Well, think back, if you've had a physics class, most likely you have had the concept of center of mass and the center of mass in mechanics, in a mechanics physics lecture, had this expression here. Mathematically, what we're looking at here is a center of mass calculation where we have replaced the mass by the intensity of the X-ray. So we have this equation that gives us the position of the X-ray in the scintillation crystal, and we can measure clearly with different intensities in the photomultiplier tubes' position with a precision that's higher than the physical dimensions of photomultiplier tubes.

Notes

Summary

5m 33s

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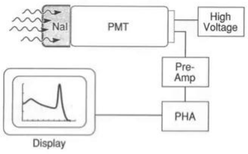


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**Photodetectors for Nuclear Medical Imaging**
William W. Moses ,Lawrence Berkeley National Laboratory Department of Functional Imaging June 20, 2008

This is technology that was developed in the 1960s. It's actually named the "Anger Positional Network." It's named after gentleman Anger and has nothing to do with the term "anger" as such, so it's *nomen est omen* here.

Notes

Summary

7m 05s