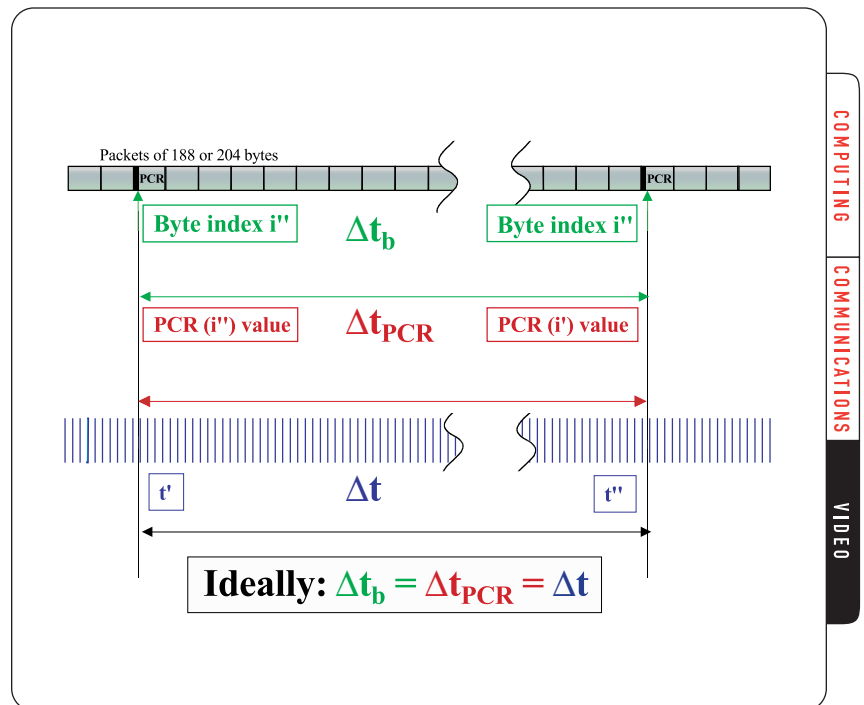


# A Layman's Guide to PCR Measurements



## ► PCR Measurements – What are the problems and what's the solution?

Program Clock References (PCRs) provide the means for a digital TV receiver to lock its decoded video output to the video source present at the input to an encoder. The subject of PCR measurement is often misunderstood. This technical brief describes impairments that affect the PCR and appropriate measurement techniques.

### What is the problem?

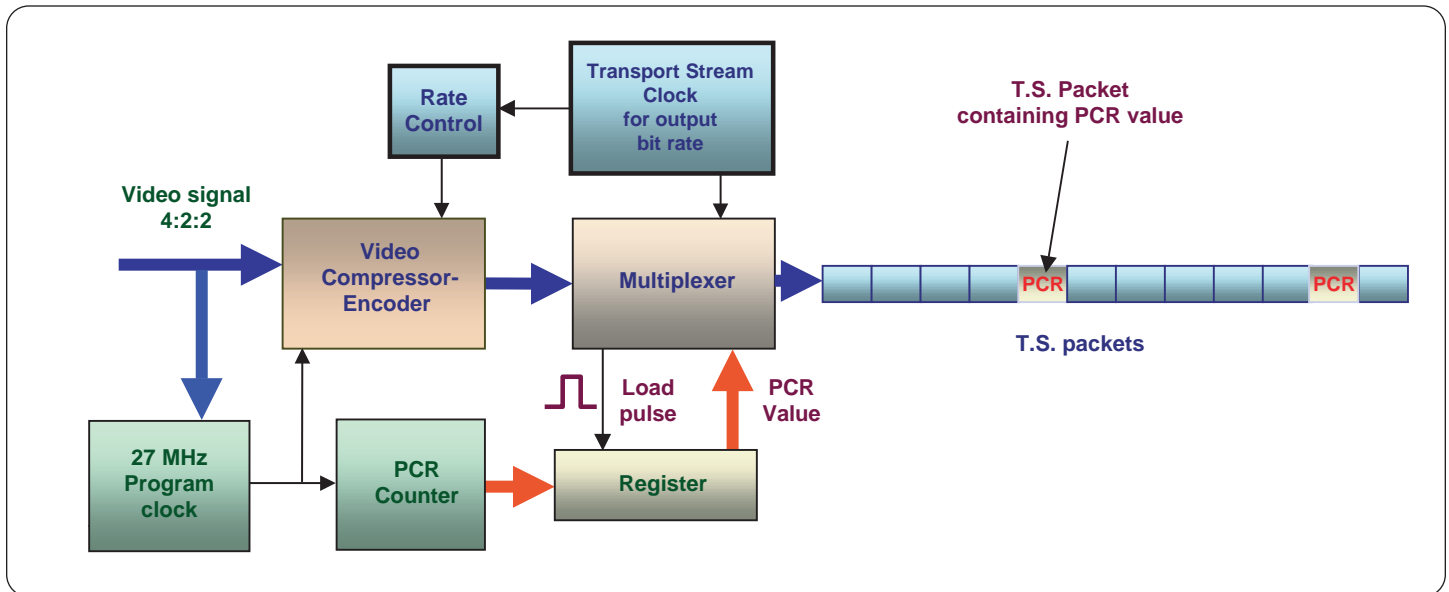
Program Clock Reference (PCR) measurements have been open to potential misinterpretation from the outset. The key specification, from ISO/IEC13818-1, which became well known throughout the industry, was for a tolerance for generated PCR values of  $\pm 500$  ns. DVB inherited this and included it as part of its Measurement Guidelines – ETR290. While the guidelines indicated clearly that this measurement was not intended to include any transmission impairments, no real

alternatives were available for assessment of PCR jitter. Subsequent operator experience with real systems led to a demand for refinement and greater clarification of PCR measurements – these form part of the revised ETR290, TR 101 290.

This document is intended to provide an overview of these new PCR measurements. It describes why three additional measurements that together provide a very clear and valuable view of overall system performance have supplemented the original measurement.

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► **Figure 1.** Insertion of PCRs at an encoder/multiplexer.

## What are PCRs? How are they inserted and used? Why are they important?

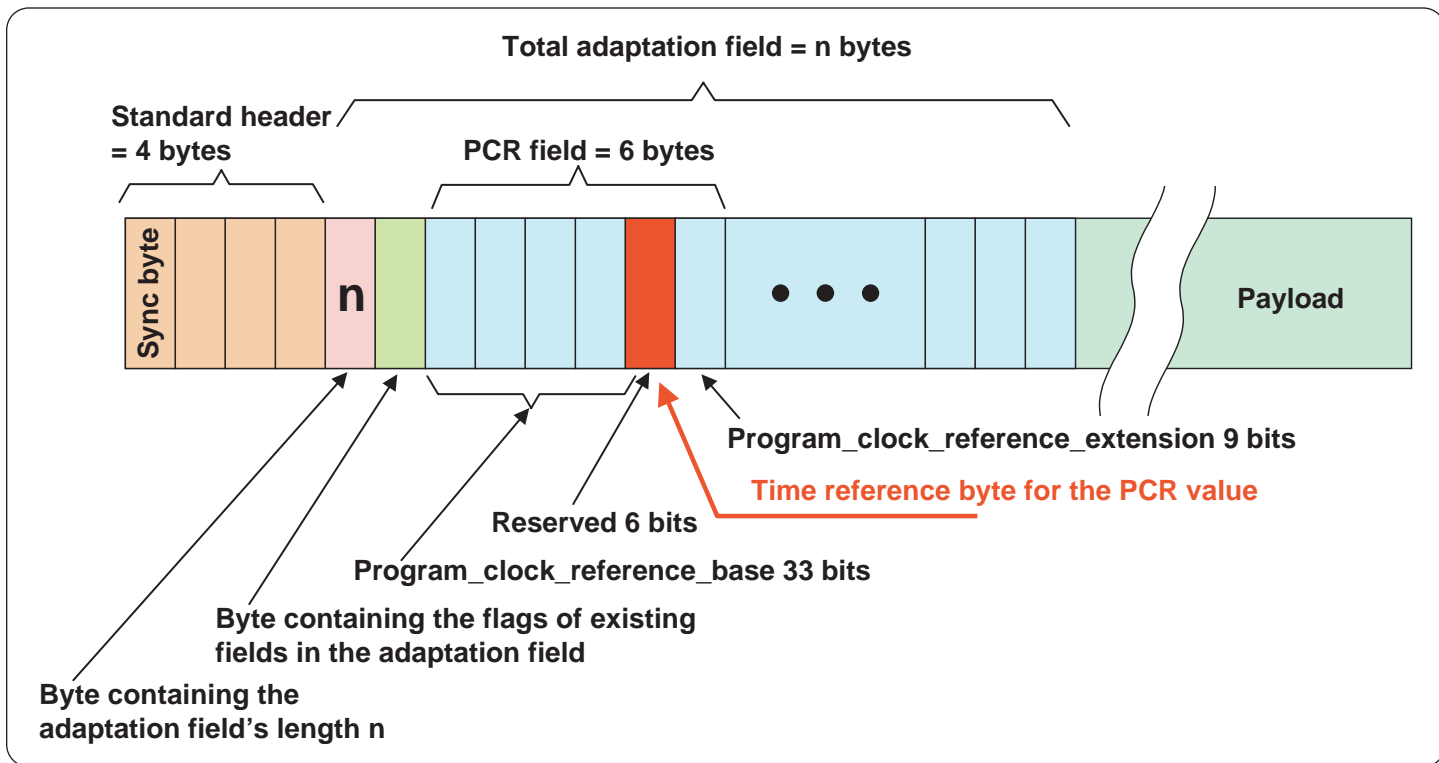
PCRs provide a means for a digital TV receiver to lock its decoded video output to the video source present at the input to an encoder. At the encoder/multiplexer, a program clock is locked to the incoming video. Since SD video (625 line 50 Hz, or 525 line 59.94 Hz) can be referenced to a 27 MHz clock, the program clock is also 27 MHz. PCRs are snapshots of a counter, driven by this program clock, that are inserted into packets within the Transport Stream (TS) at more or less regular intervals (ISO/IEC13818-1 specifies an interval of 100 ms, while DVB recommends 40 ms).

This process is shown in Figure 1 where the TS at the output of the multiplexer includes the encoded video in packets, but also includes some packets that contain PCR values. The exact value of each PCR is determined by its exact location within the TS. (Note that the TS clock

is not related at all to the program clock. Also note that a multi-program TS generally contains PCRs for each program.)

The header of a packet containing a PCR is shown in Figure 2. A total of six bytes are used with a time reference defined as shown. The multiplexer must ensure that the PCR value inserted in the TS reflects its final time position within the TS.

At the receiver, the PCRs are recovered from the TS and the counter values are compared with a similar counter driven from a locally generated 27 MHz clock. Any differences between the received counter value and the locally-generated counter value can be used to drive a Phase-locked Loop (PLL) that controls the local clock. Obviously the level of differences between the clocks will cause a greater or lesser change to the locally generated clock, with the characteristics of the PLL defining the actual changes. Small changes at low frequencies may be tracked by the PLL, whereas changes at higher frequencies may not be.



► **Figure 2.** Structure of transport stream packets containing PCRs.

The receiver's locally generated 27 MHz clock will be used to regenerate video at its output. Any changes in the frequency of this clock may be transferred to the video at its output as equivalent timing impairments in the video. While some devices such as consumer TV displays may be able to accept these, other devices such as professional recorders may not, causing the system to lose lock with a resultant loss of program.

In a similar way, a re-multiplexer may regenerate local program clock(s) for re-stamping of PCRs at its output. Any timing impairments present at its input may be transferred to the output. These, together with new impairments that may also be generated within the re-multiplexer itself, can cause problems at subsequent stages in the chain. PCRs are vital to error-free reception of program material within DVB systems, and timing impairments in PCRs can cause program loss.

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## What can go wrong with PCRs? What impairments can there be?

We can split PCR problems into two categories. The first addresses the ways in which PCRs are generated and modified in any re-multiplexing situation. A second category of PCR measurements addresses impairments in the medium used to transmit the TS.

### PCR generation (and re-generation)

PCRs are samples of a 27 MHz clock; therefore, there is an inherent granularity of 37 ns representing a single clock cycle. So, the accuracy of any inserted PCR cannot be greater than 37 ns. Additionally, the PCR insertion mechanism in a multiplexer has to assess the exact position of the PCR within the TS so that it may insert the correct value. Any miscalculation at this point will lead to inaccuracies in the PCR. A re-multiplexer will have to change relative positions of packets in a TS. Any position change must also be reflected in appropriate changes in reinserted PCR values.

Thus, PCR accuracy reflects inaccuracies due to the granularity of the 27 MHz clock, and incorrect calculation of the inserted (or reinserted) value by a multiplexer (re-multiplexer).

### PCR transmission

As noted above, an assumption can be made in measurements of PCR accuracy that the TS clock seen by the receiver is perfect. However, it is clear that any variation in the arrival time of a PCR at a receiver/re-multiplexer caused by a timing shift in the transmission system can create exactly the same differences between the received clock sample and the locally generated clock sample. These differences will, therefore, have the same effect on the PLL and regenerated clock.

Transmission impairments of this sort may be injected at the source if the TS clock at the originating coder/multiplexer is unstable, or may be generated within a distribution network. Cell delay variation at an ATM layer, and pointer shift in an SDH network resulting in transmission clock variations at a PDH layer, are examples of mechanisms that can introduce PCR transmission impairments.

To summarize, PCR transmission impairments are introduced by changes in the clock used for transmission of the TS. These impairments are independent of and in addition to the PCR accuracy errors noted above.

A simple means to remove transmission impairments, and therefore identify PCR accuracy in the presence of transmission impairments, is to capture a stream onto a hard disk and then replay it at a constant bit rate. Assuming the clock of the TS player is stable, any transmission impairments will be removed.

Of course this is exactly what a network adaptor attempts to do when it extracts a TS from an ATM-based network and provides this to an external device. Its PLL for the transmission clock and associated buffer will attempt to reduce transmission impairments to a minimum.

## What measurements can be made?

As noted earlier, PCR tolerance is specified in ISO/IEC13818-1 as  $\pm 500$  ns, but with the caveat, "This inaccuracy may be due to imprecision in the PCR values or to PCR modification during re-multiplexing. It does not include errors in packet arrival time due to network jitter or other causes."

ETR290, which has been well accepted as an excellent reference to measurements in DVB systems, included this tolerance as the PCR accuracy measurement (2.4 in the three priority levels of ETR290 monitoring).

Subsequent experience demanded a revision to ETR290 and TR 101 290 has now superseded it. Among other changes, this standard now addresses transmission impairments on PCRs and provides a full and very useful suite of measurements.

TR 101 290 includes four PCR-related measurements, one of which is the original PCR accuracy measurement defined as:

- **PCR accuracy (PCR\_AC)** – represents inaccuracies in the 27 MHz clock contained within the received PCRs, but does not include any transmission timing impairments. Measurement is made using estimated PCR arrival times calculated from their byte position within the transport streams.

This measurement is valuable in determining the performance of a single element in a DVB network, such as an encoder/multiplexer, but is of little value in making measurements in real distribution networks where transmission impairments may be dominant.

Two additional measurements address the need to include transmission impairments and are made using actual PCR arrival times.

- **PCR drift rate (PCR\_DR)** – represents the rate at which low frequency changes of the 27 MHz clock contained within the PCRs occur, measured against a stable external reference – therefore including any transmission timing changes.
- **PCR overall jitter (PCR\_OJ)** – represents high-frequency changes of the 27 MHz clock contained within the PCRs, measured against a stable external reference – therefore including any transmission timing changes.

**PCR drift rate (PCR\_DR)** measurements indicate low-frequency errors in PCRs<sup>1</sup> and include errors from both PCR generation and regeneration as well as arrival time errors caused by transmission impairments. An example follows that demonstrates the importance of PCR drift rate:

Consider again a local clock regenerator controlled by a PLL. The frequency of the signal at the output of the regenerator should track the incoming signal frequency. With slow changes in the frequency of the incoming signal, the PLL will respond and the local generator will track the incoming signal. As the incoming signal changes at an increasing rate, the PLL will be less able to track, and the locally generated signal will eventually lose lock with resultant program loss. PCR drift rate measurement offers a means of determining how well a de-multiplexer/decoder, or re-multiplexer can be expected to lock its own

program clock to the PCRs contained in an incoming TS. (Note that the measurement is one of drift rate rather than absolute frequency. A PLL at the receiver may be expected to lock to a system clock that has a fixed error in its frequency – it is fast changes, or large drift rates, that cause problems.)

**PCR overall jitter (PCR\_OJ)** is the third measurement and arguably the most important. It is an overall measurement of high frequency errors in PCRs and, again, includes errors from both PCR generation and regeneration, as well as arrival time errors caused by transmission impairments. One example of where this transmission impairment could be introduced is within an RF demodulator in a receiver. The TS clock that is regenerated within the receiver, and is used within the de-multiplexer/decoder, may include substantial high-frequency variations that could directly impact the recovered PCRs. A second example is an ATM network adaptor that fails to filter out the effect of cell delay variation. In both cases, the PCR arrival time errors seen by the decoder in its recovered PCRs may be many times greater than the  $\pm 500$  ns limit imposed on PCR accuracy.

Any decoder is reliant on received PCRs to regenerate its program clock correctly and provide a stable video output. In the same way, any re-multiplexer relies on received PCRs in order to accurately re-stamp PCRs at its output. The arrival time of these PCRs is critical; therefore, measurement of overall jitter (PCR\_OJ) that includes both arrival time errors and accuracy errors is imperative.

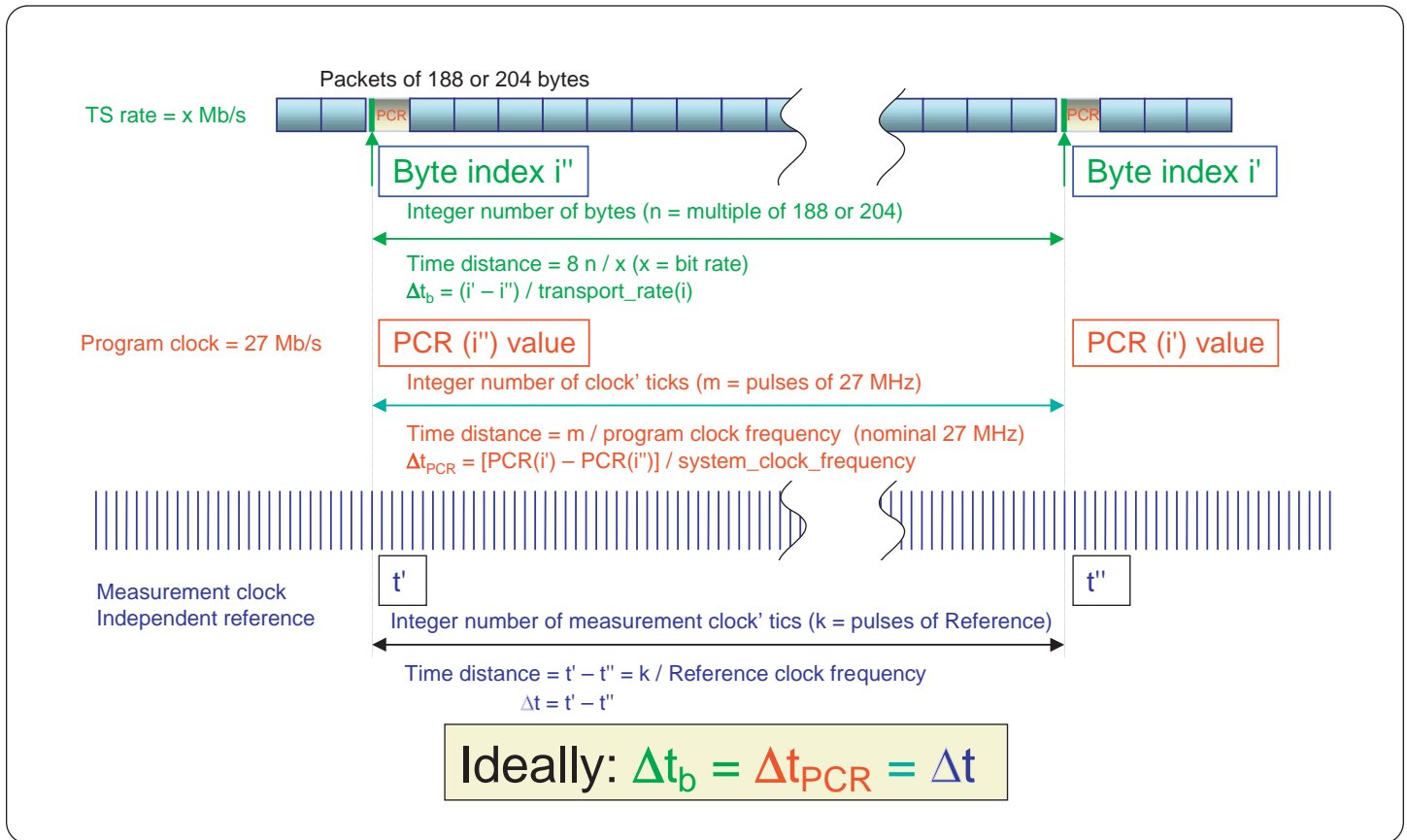
In ideal operational systems, transmission impairments should be designed out. But often, typical distribution networks now include cascaded links, remultiplexers, ATM layers, etc., all of which have the capability of introducing errors. PCR\_AC is of value for measurements directly at the output of a multiplexer, but can be very misleading for operational monitoring within a network, since by definition it inherently filters out all transmission impairments.

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<sup>1</sup> Determination of frequency break points between PCR\_DR and PCR\_OJ is beyond the scope of this guide, but is addressed in depth in papers referred to in the references.

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► **Figure 3.** Illustration of the clocks embedded in a TS.

PCR\_DR and PCR\_OJ are the only measurements that can highlight transmission impairments, thereby facilitating fault isolation and repair.

The final measurement addresses the absolute accuracy of the 27 MHz clock contained within the PCRs.

- **PCR frequency offset (PCR\_FO)** – represents the frequency offset of the 27 MHz clock contained within the PCRs, measured against a stable external reference.

An alternative means of understanding the difference between PCR\_AC and PCR\_OJ is shown in Figure 3. This illustrates that the time interval between two PCRs for a given program can be counted in three different ways. First, by a clock that is independent to the TS itself, represented by  $\Delta t$ . Second, by counting the number of bytes between the two PCR fields and dividing by the TS byte rate, represented by  $\Delta t_b$ . Or finally, by subtracting the two PCR counter values (number of 27 MHz clock ticks of the original program clock) and dividing by the measured frequency of the original program clock, represented as  $\Delta t_{\text{PCR}}$ .

Clearly, all three methods should ideally provide the same result, but all three measurements may be different.

A comparison between  $\Delta t_{\text{PCR}}$  and  $\Delta t_b$  results in a measurement of PCR accuracy (PCR\_AC). The difference between these two values depends on the accuracy of the multiplexer or the re-multiplexer and is not affected by transmission impairments.

A comparison between  $\Delta t_{\text{PCR}}$  and  $\Delta t$  results in a measurement of PCR overall jitter (PCR\_OJ). The difference between these two values includes variations in the time at which the PCR values actually arrive at a decoder/re-multiplexer and therefore includes all the impairments caused by the network, plus the accuracy errors. There is no differentiation between impairments caused by the network and accuracy errors, hence the name overall jitter. This is the total jitter seen by the decoder/re-multiplexer and may be a major cause of problems.

## Conclusions

It can be seen that measurement of PCR\_AC on its own can only provide a small part of the picture. The new measurements are vitally important in providing the broader picture, particularly in monitoring of operational networks.

As an operator monitoring a DVB distribution network, it is imperative to know what transmission impairments are present. Levels of drift rate and overall jitter, defined by PCR\_DR and PCR\_OJ, offer a means of determining the exact effects of distribution through, for example, an ATM network.

As a system designer, these measurements help qualify system components and specify network parameters for guaranteed performance.

Finally, in design and manufacturing they can help create product specifications that meet real system requirements in all conditions.

The ever-increasing complexity of DVB distribution networks has been part of the rationale behind extensions to ETR290 that are included in TR 101 290. The extension of PCR measurements to include transmission impairments is an important part of this, defining measurements to meet these new requirements.

## References

The document you have just read is what we consider to be a layman's guide to PCR measurement. An in-depth view of this, together with help selecting specific measurement filter values and determining the break point between jitter and wander, can be found in the Tektronix primer "Guide to PCR Measurements," document number 25W-14617-0.

- ▶ International Standard ISO/IEC13818-1 MPEG Systems
- ▶ ETSI Technical Report ETR290 – Measurement Guidelines for DVB Systems – May '97
- ▶ Draft ETSI Technical Report TR 101 290 – Measurement Guidelines for DVB Systems
- ▶ A Guide to MPEG Fundamentals and Protocol Analysis – document number 25W-11418-3

# A Layman's Guide to PCR Measurements

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