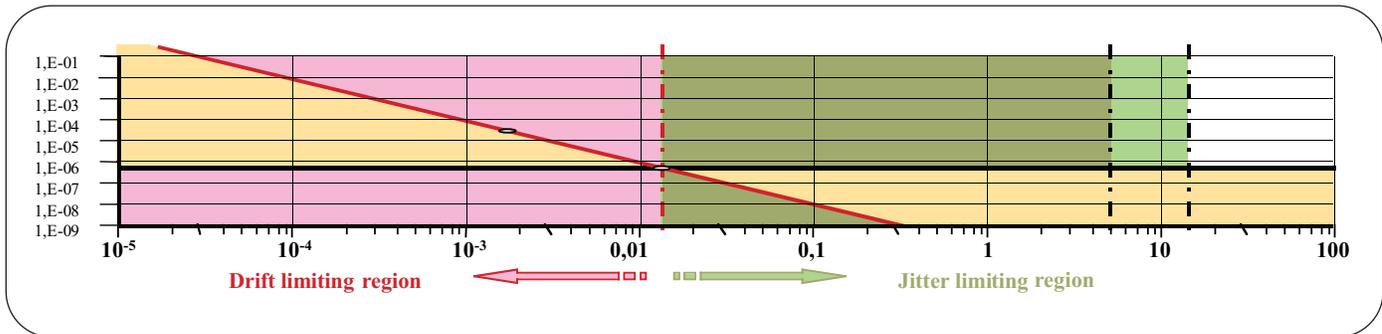


# PCR Measurements



COMPUTING

COMMUNICATIONS

VIDEO

# PCR Measurements

► Primer

## New measurements in ETR 290<sup>1</sup>

### Abstract

One of the problems for any type of synchronization procedure is the jitter on the incoming signal that is the source for the synchronization process. Television signals are subject to this general problem, and since the analog and digital forms of the TV signal differ, the problems due to jitter manifest themselves in different ways.

With the arrival of MPEG compression and the possibility of having several different TV programs sharing the same Transport Stream (TS), a mechanism was developed to synchronize receivers to the selected program. This procedure consists of sending numerical samples of the original clock frequency. Use of these samples, called the Program Clock Reference (PCR), requires a new way of looking at the effects of jitter.

Various programs in the same TS may share the same set or sequence of PCR samples if they are synchronous in the origin. However, the different programs are not necessarily related to one another. They may be non-synchronous, and in this case, each program has its own independent set or sequence of PCR samples.

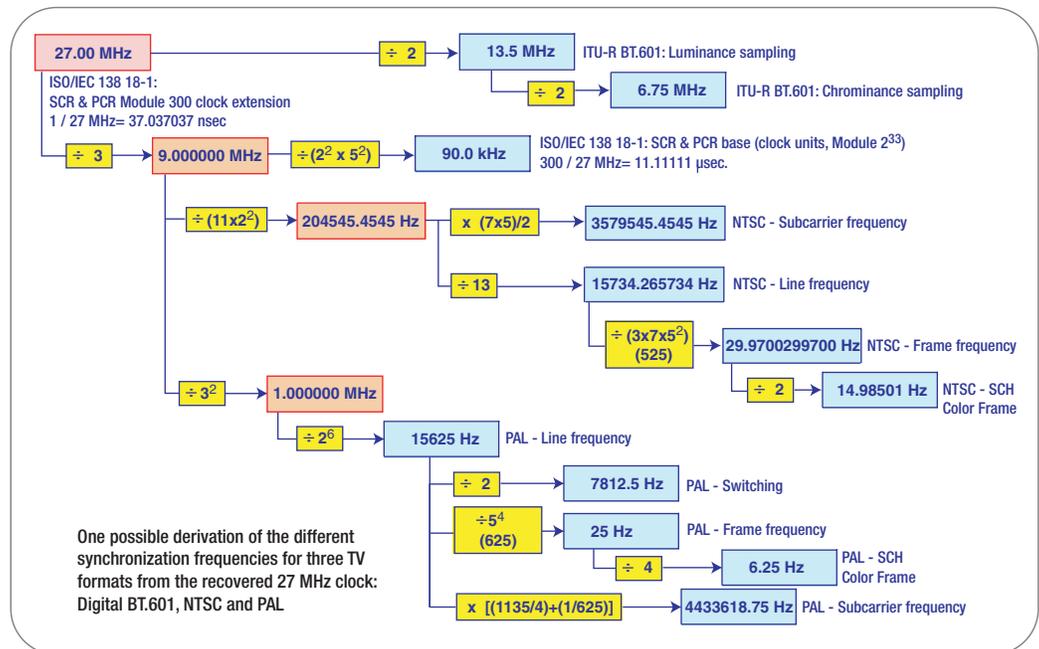
This primer, originally published for "Made to Measure 2000," describes a new procedure for jitter measurements as recommended in the updated version of the ETR290 document, TR 101 290. It is intended for engineers and technicians who routinely monitor or measure video parameters and must have confidence in the results.

## Synchronizing the Components of a Video Signal

Delivering TV pictures from studio to home entails sending various types of data: brightness, sound, information about the picture geometry, color, etc. and the synchronization data.

In analog TV systems, there is a complex mixture of horizontal, vertical, interlace and color subcarrier reference synchronization signals. All this synchronization information is mixed together with the corresponding blanking information, the active picture content, tele-text information, test signals, etc. to produce the programs seen on a TV set.

The digital format used in studios, generally based on the standard ITU-R BT.601 and ITU-R BT.656, does not need a color subcarrier reference signal because it is based on three separate components of the picture. But it still requires synchronization information for horizontal sweep (line), vertical (frame), interlace (field) and digital word (bit sync. and/or byte sync.). This new synchronization signal for words is not present in analog systems, but is needed in the digital formats to assure a good reconstruction of the clock used for picture sampling or analog to digital conversion.



► Figure 1 – Derivation from 27 MHz clock

<sup>1</sup> Tektronix has been actively involved in the development of the original ETR 290 "Measurement Guidelines for DVB Systems" document, and its updated version TR 101 290, approved by the Technical Module of DVB "Digital Video Broadcasting".

The sampling clock must be at least as precise and stable as the color subcarrier reference signal in order to produce a stable result. Many digital signals are converted to analog signals at certain points in the distribution chain, or at least at the delivery to the home receiver, to assure that existing TV sets are compatible with the new digital signals. The subcarrier frequency is then derived from the sampling clock reference. (Figure 1)

TV compression formats using MPEG-2 have, as units of information, a sequence of complete frames or fields, the Group Of Pictures (GOP). The GOP in compressed TV signals is the equivalent of the SCH Color Frame period of analog signals (four frames in PAL or two frames in NTSC).

Only two synchronization signals are needed for the compressed video signals: the time at which a frame or field should be presented on screen and the information to reconstruct the sampling clock which was used in the original signal before compression (namely 27 MHz for word synchronization). All other synchronization information needed to reconstruct the video from MPEG-2 into a digital or analog format is implicitly embedded in the compressed data.

The Presentation Time Stamp (PTS) provides frame synchronization. The PCR is used to recover the sampling clock.

### What is jitter?

Jitter is just one of the terms used to name some aspects of frequency instability.

A perfect oscillator that produces an absolutely stable frequency in the short term as well as in the long term, simply does not exist. All oscillators exhibit some kind of instability, and this can be described by different terms depending on how the oscillator is used.

In the radio frequency field with modulated carriers used for transmission of signals, it is typical to refer to the error in the frequency of the oscillator with respect to the nominal expected frequency as **frequency offset**, and slow frequency variations as **frequency drift**. **Residual FM** is used to describe faster frequency variations, and **phase noise** is used for very small frequency variations at any rate, whether fast or slow.

The terms residual FM and phase noise are used in RF applications and correspond with the terms **wander** and **jitter** when used in reference to clocks used in digital communication system.

The video industry typically uses the terms:

**Drift:** frequency error or frequency offset for static frequency errors

**Drift-rate:** the speed of the slow variations (wander)

**Jitter:** the amplitude of phase noise

In the new document TR101290 of the Digital Video Broadcasting (DVB), the corresponding terms are:

**Frequency offset (FO)**

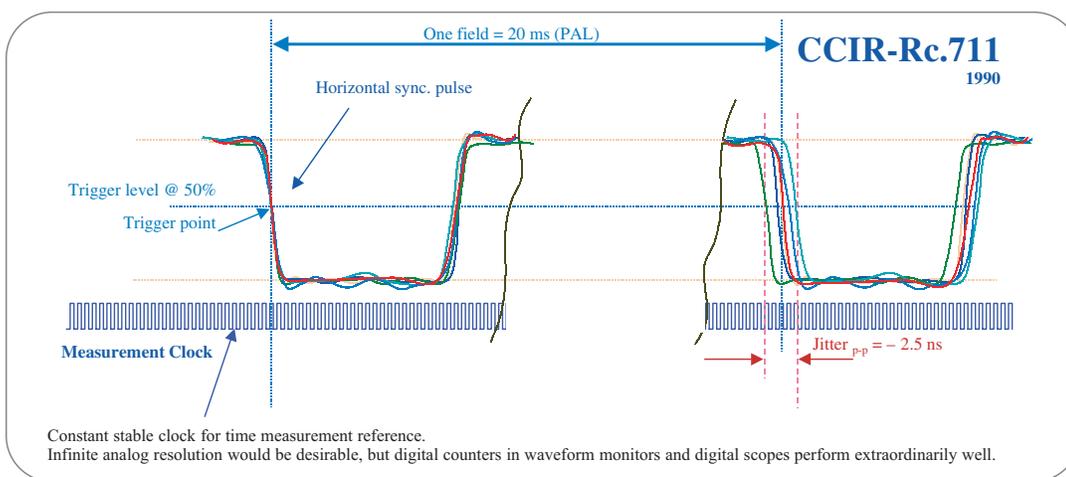
**Drift-rate (DR)**

**Overall jitter (OJ)**

An additional term, **Accuracy (AC)**, refers to the calculation of PCR values with respect to their position in the TS as measured in terms of byte index, and therefore related to the TS rate.

Accuracy relates the two independent clocks available for each program, the video rate and the TS rate.

Figures 2a and 2b show graphical interpretations of the recommendation by ITU-BT.711-1 (1990), which establishes that for analog sync signals used to synchronize TV studios using component digital formats, the timing of any leading edge of a horizontal synchronization pulse must be within  $\pm 2.5$  ns, with respect to the average value of the edges along at least one field.



▶ **Figure 2a** – Jitter as per recommendation Rc. 711

## PCR Measurements

### ► Primer

This definition seems to be clear at first, and the graphs in Figures 2a and 2b seem to represent two valid solutions to the problem of measuring jitter. However, the definition is not really clear, and the two figures are inappropriate for jitter measurement.

Neither figure discriminates between jitter and slow drift. Signals with low jitter may be classified as non-compliant because they have large but slow variations of phase. These acceptable slow variations would be considered as jitter if the procedures suggested by Figures 2a and 2b were used.

It may seem that Figure 2b is more accurate than Figure 2a, which is true in some sense. If the sweep of the waveform monitor or the oscilloscope is triggered in Automatic Frequency Control (AFC) mode, where the trigger signal is obtained from the input signal after passing through a PLL, then it seems that there is no problem. The frequency offset and the slow drift are removed by the filtering action of the PLL. However, there is now a problem in deciding what cut-off frequency the PLL should have.

The differentiation between jitter and drift-rate is defined differently for each application. For example, in communications it is common to have a demarcation frequency of 10 Hz. Frequency instabilities slower than 10 Hz are considered wander, and those above are considered jitter—regardless of the amplitude of the variations. This 10 Hz demarcation frequency has also been used as a "de facto" standard in analog video for many years. The next question is, "Can a demarcation frequency be found based on the specification?"

It has been shown that combining the specifications SMPTE RP-154 (equivalent to ITU-R BT.711-1) and SMPTE-170M, a more reasonable demarcation frequency is 0.5 Hz, according to Tom Tucker in "Measuring Wander in Video Distribution Systems." With the advent of digitally compressed video using MPEG-2, the reference clocks are not simple pulses anymore and are thought of differently for the transmission of synchronization signals to a destination. For DVB-defined distribution systems and in general for any MPEG-2 use of digital video, there is a more appropriate frequency (12 mHz) for the demarcation between jitter and drift-rate. Jitter may be defined for frequency variations, period variations or phase variations, and the variations may be classified as fast or slow, big or small, periodic or random.

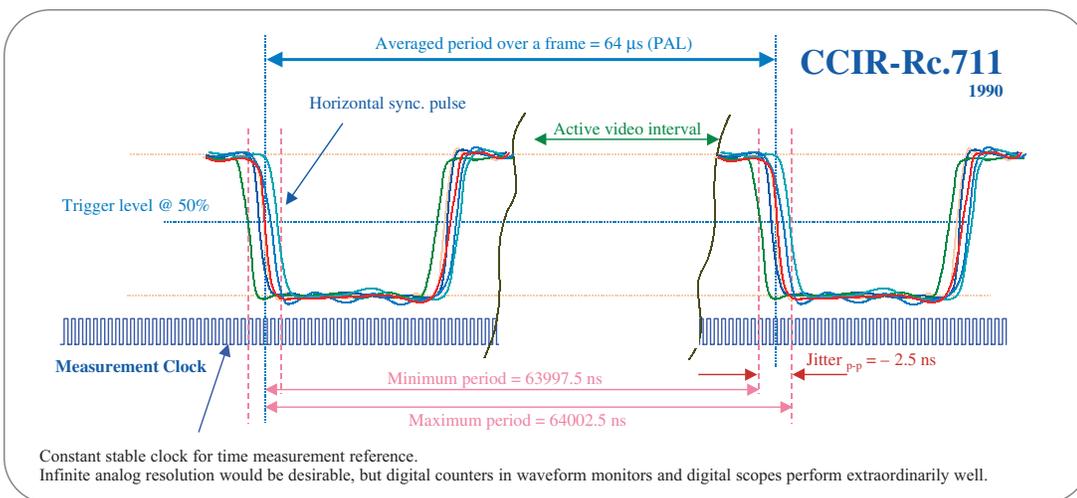
## MPEG-2 Systems

The ISO/IEC 13818 standard defines the compression modes for video and audio signals, as well as for the multiplexing of the programs.

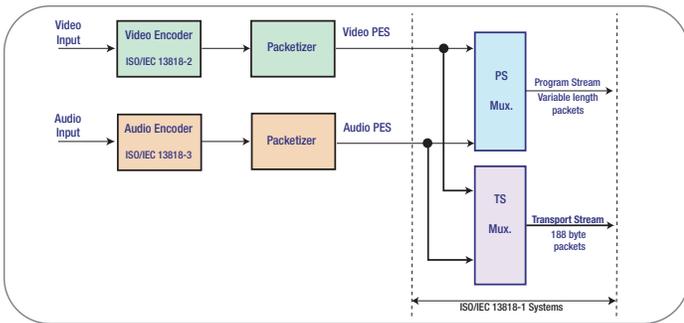
### ISO/IEC 13818-1 Systems:

This part of the standard defines the multiplexing of the Packetized Elementary Streams (PES) to create either a Program Stream (PS) or a Transport Stream (TS).

**Program Stream:** This is analogous to the ISO/IEC 11172 Systems layer (MPEG-1). It results from combining one or more streams of PES packets, which have a common time base, into a single stream.



► **Figure 2b** – Another interpretation of Rc. 711



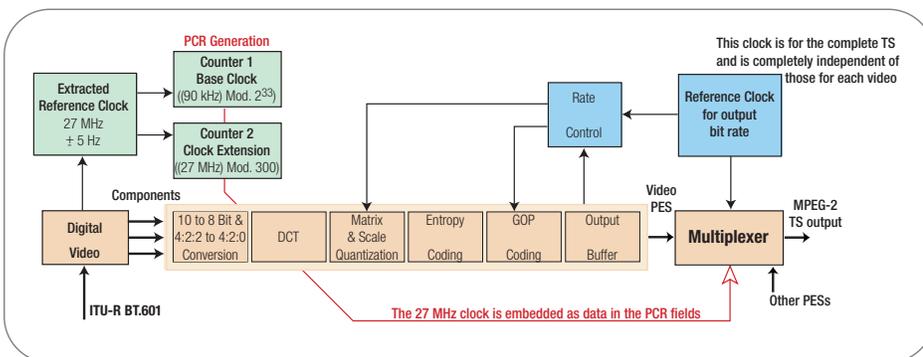
▶ **Figure 3 – MPEG-2 Systems**

There may be applications that require the elementary streams, which comprise a single program, to be in a separate stream, not multiplexed with other programs. In this case the values encoded in the System Clock Reference (SCR) fields of the various PES packets making up the program must be consistent. PES packets may be of variable and relatively great length.

**Transport Stream:** This combines one or more programs into a single stream that may have one or more independent time bases. All of the PES packets that make up a single program (or service) share a common time base. Each program or service may have its own time base. TS packets are 188 bytes in length. DVB systems use only transport streams, not program streams.

### PCR generation

When the information on output bit rate and PCR interval (the DVB recommends this interval be not greater than 40 ms) has been given to a multiplexer, it can then calculate which transport packets should contain the PCR values, and what those values should be.



▶ **Figure 4 – Generation of PCR values from a 601 digital signal**

The PCR value is encoded into two fields called PCR\_base and PCR\_ext and indicates the time  $t(i)$ , in units of the 27 MHz clock, where  $i$  is the index of the byte containing the last bit of the program\_clock\_reference\_base field. The PCR(i) is calculated as follows:

$$PCR(i) = PCR\_base(i) \times 300 + PCR\_ext(i)$$

$$PCR\_base(i) = [(system\_clock\_frequency \times t(i)) \text{ DIV } 300] \text{ MOD } 2^{33}$$

$$PCR\_ext(i) = [(system\_clock\_frequency \times t(i)) \text{ DIV } 1] \text{ MOD } 300$$

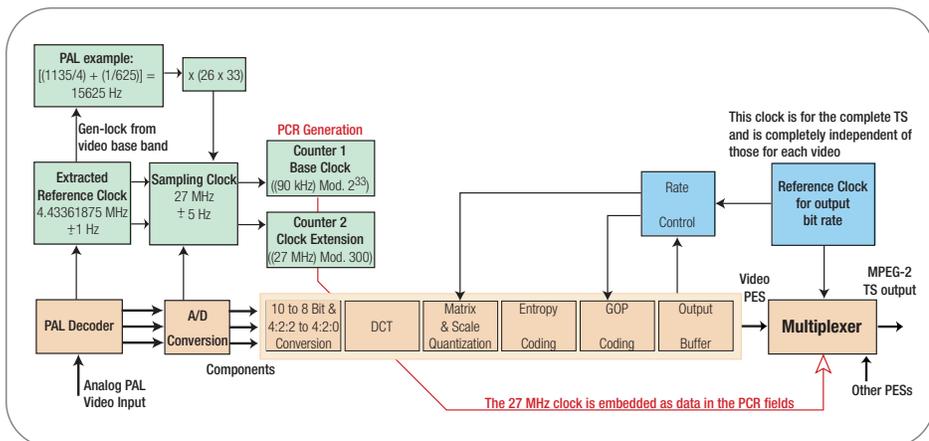
Figure 4 shows a conceptual block diagram of the process of creating and inserting PCR values when encoding a digital 601 type of signal, while Figure 5 shows the equivalent for an analog PAL signal.

Notice that in both cases the master clock, which is encoded as PCR values in the corresponding PCR fields, is extracted from the incoming video itself. No stable master reference is used. In fact, only the incoming video signal is used to extract the reference, and the decoder at the end of the chain must lock precisely to this clock in order to properly decode and display the signal.

In the examples shown, the 27 MHz clock is extracted from the 27 MHz or 270 MHz component of the digital signal or from the subcarrier of the composite analog signal, that is, 4.43 MHz for PAL or 3.58 MHz for NTSC. This 27 MHz reference clock extracted from the video and used in the MPEG-2 compression process may exhibit a small offset from the nominal frequency. With time, it may also exhibit slow variations in its frequency, and the speed, or drift-rate, of these variations is of interest. It may also exhibit small and fast frequency variations called jitter, whose amplitudes are the subject of measurement.

## PCR Measurements

### ► Primer



► **Figure 5** – Generation of PCR values from an analog PAL signal

Notice in Figures 4 and 5 that in one TS there are at least two independent clocks available for each program: the program related PCR values and the TS rate itself. The decoder at the receiver end should lock to the TS rate and the reconstructed video signal should lock to the PCR values.

Take care when measuring the measurement reference. For frequency offset, drift-rate and overall jitter, you should use an independent, accurate and stable time reference. For PCR accuracy measurements, use the nominal TS rate or the average of the measured TS.

## Sources of jitter

Any and all frequency variations that are present in the incoming video signal are passed on to the encoded PCR values. However, this is not the only source of jitter in the PCRs that are embedded in a TS. Following is a list of possible sources for PCR error and PCR jitter:

1. Algorithm error in the calculation. In this case, it is called PCR accuracy in ISO/IEC 13818-1 and should be limited to  $\pm 500$  ns.
2. Number rounding at the moment of time stamping, (granularity of counting "i" bytes and counting "k" pulses). This may occur at the encoding-multiplexing stage or at re-multiplexing and re-stamping.
3. Relocation or movement within the TS of the packets carrying the PCR information. This may occur in re-multiplexing stages where the input rate and the output rate are the same, and after local program insertion, no re-stamping is carried out.
4. Relocation or movement within the TS of the bytes carrying the PCR information when transporting the TS data through packet switched networks:
  - 4.1 PDH stuffing process
  - 4.2 ATM cell allocation
  - 4.3 SDH/SONET pointer movements
  - 4.4 ASI stuffing bytes insertion
  - 4.5 Common Interface gap insertion/deletion, if the extracted TS from a decoder is used again for transmission
  - 4.6 Re-multiplexing enroute
5. Physical jitter existing in the clocks used for the PCR time stamping in the multiplexer and/or the re-multiplexer (either the clock to create the TS rate or the video SCR).

## Limits from ISO/IEC 13818-1

To separate jitter from drift, there is no rule or physical law that determines how low or high the frequency of any perturbation must be to declare it to be one or the other. The definition is a matter of agreement in the industry. All measurement equipment uses that agreed-upon value to separately measure jitter and drift.

You might wonder why anyone would want to measure jitter and drift separately. The main reason is that they represent two different aspects of frequency variations. For jitter the amplitude is most important; for drift-rate, the speed of the variation is of primary interest.

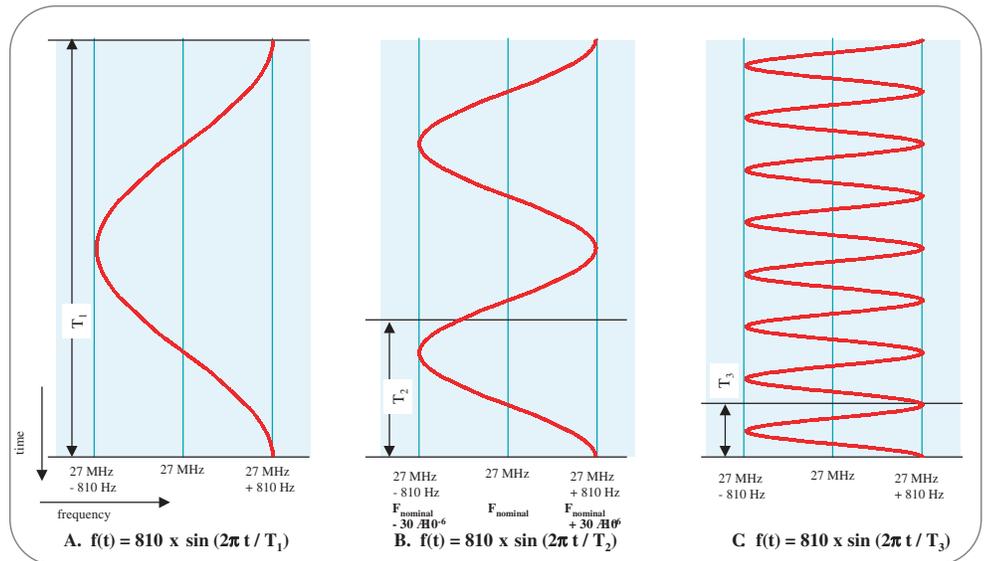
Another difference is the fact that the recovery circuitry will be able to follow and track the frequency drift, both static drift and slow drift, but not jitter. In fact, jitter is removed from the recovered clock, but remains in the signal. The jitter must be controlled and kept as small as possible, and consequently measured separately from drift.

From the specifications set forth in ISO/IEC 13818-1, it is possible to define a limit mask for frequency variations from the nominal 27 MHz.

**Frequency offset** is the difference between the actual value and the nominal frequency of the clock (27 MHz). The limit is set to  $\pm 810$  Hz. Converting this value into relative or normalized units results in  $810 / 27 \times 10^6 = 30 \times 10^{-6}$ . This means that the frequency of the clock, at any moment, should be  $27 \text{ MHz} \pm 0.003\%$ , or  $27 \text{ MHz} \pm 30 \text{ ppm}$ . Making the limit of the frequency offset relative has the advantage of obtaining a limit that is valid for any reference clock used to synthesize the nominal clock of 27 MHz. For example, the frequency error in hertz of a 270 MHz serial clock derived from the 27 MHz system clock can be divided, or normalized, by 270 MHz to determine if the frequency offset is within 30 ppm.

$$27,000,000 - 810 \leq \text{system\_clock\_frequency} \leq 27,000,000 + 810 @ 27 \text{ MHz}$$

$$\text{Frequency tolerance} = \pm 30 \text{ ppm}$$



▶ **Figure 6 – The frequency limit**

By itself the frequency limit is not enough to assure synchronization of clocks. Rapid variations within  $\pm 30$  ppm could cause a failure to lock. (The DVB, in document ETR 154 section 4.1.3, recommends a frequency error limit of 5 ppm. This represents a  $\pm 135$  Hz limit instead of  $\pm 810$  Hz.)

Figure 6 shows three examples of frequency instability in which the variation of the frequency around the nominal value is sinusoidal, and all three are pushing the limits, without exceeding them. However, the example above, part C, puts more stringent conditions on an oscillator that may try to synchronize to it than the other two. The speed of change at the zero crossings of the sinusoids is much higher as the frequency increases, so it is convenient to define a maximum slope to further characterize the stability of a clock.

Frequency **drift-rate**, or frequency rate of change, is the "speed" at which the frequency of a clock varies with time. In other words, it is the first derivative of the instantaneous frequency with respect to time; it is also the second derivative of phase with respect to time.

The limit is set to 75 mHz for the 27 MHz clock. It can be converted into a relative limit by dividing by 27 MHz, which produces a result of  $75 \times 10^{-3} / 27 \times 10^6 = 2.7778 \times 10^{-9}/\text{sec}$ .

$$\text{Rate of change of system\_clock\_frequency} \leq 75 \times 10^{-3} \text{ Hz/ sec @ 27 MHz}$$

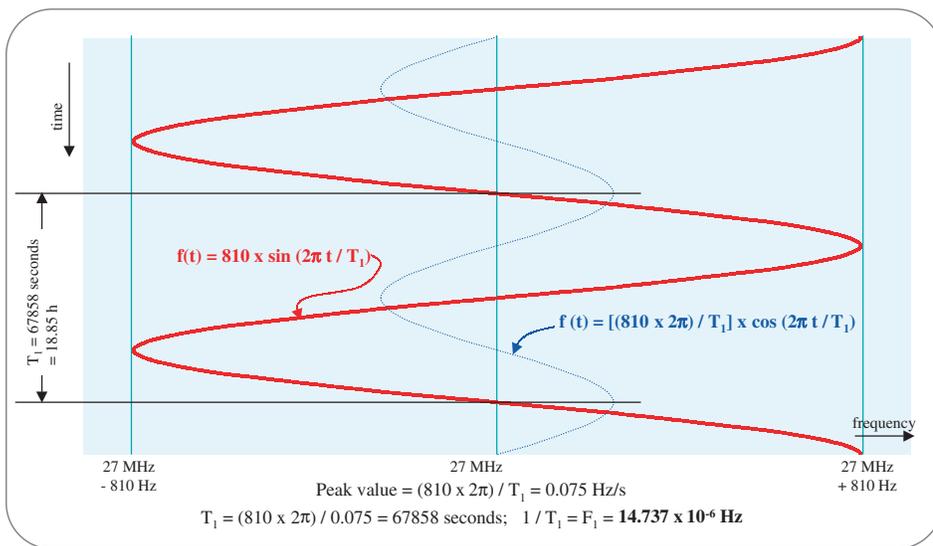
$$\text{Drift-rate tolerance} = \pm 2.7778 \times 10^{-9}/\text{sec @ 1 Hz}$$

## PCR Measurements

► Primer

This means that the maximum rate of change allowed for the clock frequency is  $\pm 0.002778$  ppm/sec of the nominal.

This result can also be represented as  $\approx 0.001\%$ /hour or 10 ppm/hr.



► **Figure 7** – The frequency limit combined with drift-rate limit

Figure 7 shows how to combine the two limits to find the maximum sinusoidal frequency that may be allowed, to explore the complete range of frequency offset while maintaining the maximum drift-rate by obtaining the first derivative of the sinusoid. This maximum frequency is about 15  $\mu\text{Hz}$ .

Suppose, for example, that part B of Figure 6 represents a frequency of 15  $\mu\text{Hz}$ . Any frequency lower than that, as represented in part A, may explore the whole range, but any higher frequency, as represented in part C, cannot have such amplitude without exceeding the drift-rate limit. The higher the frequency above the calculated 15  $\mu\text{Hz}$ , the lower the peak-to-peak amplitude of the variation allowed.

### Phase limit:

However, as will be shown when a practical mask is derived, it is convenient to define a third limit representing the absolute value of the error in the phase that represents the maximum error of a PCR value with respect to

its time position in the TS.

The maximum limit for the phase is established by ISO/IEC 13818-1 as  $\pm 500$  ns. This value is an absolute limit for the generation of PCRs and does not include network-induced jitter.

### Phase tolerance = $\pm 500$ ns

ISO/IEC 13818-9 (extension for real time interface for systems decoders) specifies in clause 2.5 (Real-Time Interface for Low Jitter Applications) a limit for network transfer jitter equal to 50  $\mu\text{s}$ .

### Low jitter applications tolerance = $\pm 25$ $\mu\text{s}$

The limits for frequency offset and drift-rate of the system clock are represented by the values of the corresponding PCR fields. These values include the effects of the system clock and any possible errors in the PCR calculation. The limit of 500 ns

is not imposed on the system clock, but on the accuracy representing the PCR values with respect to their position in the TS. The PCR errors are equivalent to phase and jitter errors when the PCRs are used at the decoding point to reconstruct the system clock.

### Equations for the three limits

The waveform of the phase modulation may have any shape that can be analyzed as a composition of sinusoidal waveforms of various amplitudes and phases. Also, the clock may be a pulsed signal, and in that case, the formulas below apply to the fundamental component of such a periodic signal.

For example, the equation for a sinusoidal clock with sinusoidal phase modulation can be written as:

$$\textcircled{1} F_{\text{clk}}(t) = A \times \sin [\omega_c \times t + \Phi(t)] = A \times \sin [\omega_c \times t + \Phi_p \times \sin (\omega_m \times t)]$$

where:

$\omega_c$  = nominal angular frequency of the program clock, ( $\omega_c = 2\pi \times 27$  MHz)

$\Phi(t)$  = phase modulation function

$\Phi_p$  = peak phase deviation in radians

$\omega_m$  = phase modulating angular frequency in units of radians/sec

The **instantaneous phase** of the clock has two terms as:

$$\textcircled{2} \Phi_i(t) = \omega_c \times t + \Phi(t) = \omega_c \times t + \Phi_p \times \sin (\omega_m \times t)$$

where:

$\Phi_i(t)$  = instantaneous phase of the clock, in radians.

The **instantaneous angular frequency** of the clock is found as the first derivative of the instantaneous phase as:

$$\textcircled{3} \omega_i(t) = \Phi_i'(t) = d \Phi_i(t) / d t = \omega_c + \Phi_p \times \omega_m \times \cos (\omega_m \times t)$$

where:

$\omega_i(t) = \Phi_i'(t)$  = instantaneous angular frequency of the clock, in radians/sec

The **drift-rate**, or frequency rate of change, is given by the first derivative of the angular frequency, or the second derivative of the phase as:

$$\textcircled{4} r_i(t) = \omega_i'(t) = d \omega_i(t) / d t = -\Phi_p \times \omega_m^2 \times \sin (\omega_m \times t)$$

where:

$r_i(t) = \Phi_i''(t)$  = instantaneous drift-rate of the clock, in radians/sec<sup>2</sup>.

### Mask with equations of limits

A limit mask can be derived as a group of functions representing the limit specifications.

From the instantaneous **phase equation** (2), it can be seen that the maximum peak value of phase modulation is  $\Phi_p$ , which can be compared to the limit set by ISO/IEC 13818-1.

The phase equation may be found as:

$$\textcircled{5} \Phi_p = \omega_c \times T_{\text{max}} = 2\pi \times 27 \text{ MHz} \times 500 \times 10^{-9} \text{ seconds} = 84.823 \text{ radians}$$

where:

$T_{\text{max}}$  = maximum time error of clock edge =  $500 \times 10^{-9}$  seconds

From the instantaneous angular frequency equation (3), it can be seen that the maximum peak value of angular frequency offset is given by  $\Phi_p \cdot \omega_m$  which can be compared to the limit set by ISO/IEC 13818-1 of 810 Hz.

The maximum angular frequency deviation from the nominal is:

$$\Phi_p \times \omega_m = 2\pi \times 810 \text{ radians/s} = 5089.4 \text{ radians/s}$$

The **frequency equation** for peak phase error as a function of modulation frequency may be found by dividing by  $\omega_m$ :

$$\textcircled{6} \Phi_p = 2\pi \times 810 / \omega_m = 5089.4 / \omega_m \text{ (radians)}$$

[For DVB, per ETR 154:  $\Phi_p = 2\pi \times 135 / \omega_m = 848.23 / \omega_m$  (radians)]

From the instantaneous drift-rate equation (4), it can be seen that the maximum peak value of angular frequency drift-rate is  $\Phi_p \times \omega_m^2$ , which can be compared to the limit set by ISO/IEC 13818-1 of 75 mHz/sec.

$$\Phi_p \times \omega_m^2 = 2\pi \times 0.075 \text{ radians /sec}^2 = 0.4712 \text{ radians/sec}^2$$

By dividing by  $\omega_m^2$ , the **drift-rate equation** for peak phase error as a function of modulation frequency may be found as:

$$\textcircled{7} \Phi_p = 2\pi \times 0.075 / \omega_m^2 = 0.4712 / \omega_m^2 \text{ radians}$$

All three equations may be normalized by dividing by  $2\pi \cdot 27$  MHz.

The **phase equation** becomes:

$$\textcircled{5a} T_{\text{max}} = \Phi_p / 2\pi \times 27 \times 10^6 = 84.823 / 2\pi \times 27 \times 10^6 = 500 \times 10^{-9} \text{ seconds}$$

The **frequency equation** becomes:

$$\textcircled{6a} Tf(\omega_m) = \Phi_p / 2\pi \times 27 \times 10^6 = 2\pi \times 810 / (2\pi \times 27 \times 10^6 \times \omega_m) = (30 \times 10^{-6} / \omega_m) \text{ seconds}$$

# PCR Measurements

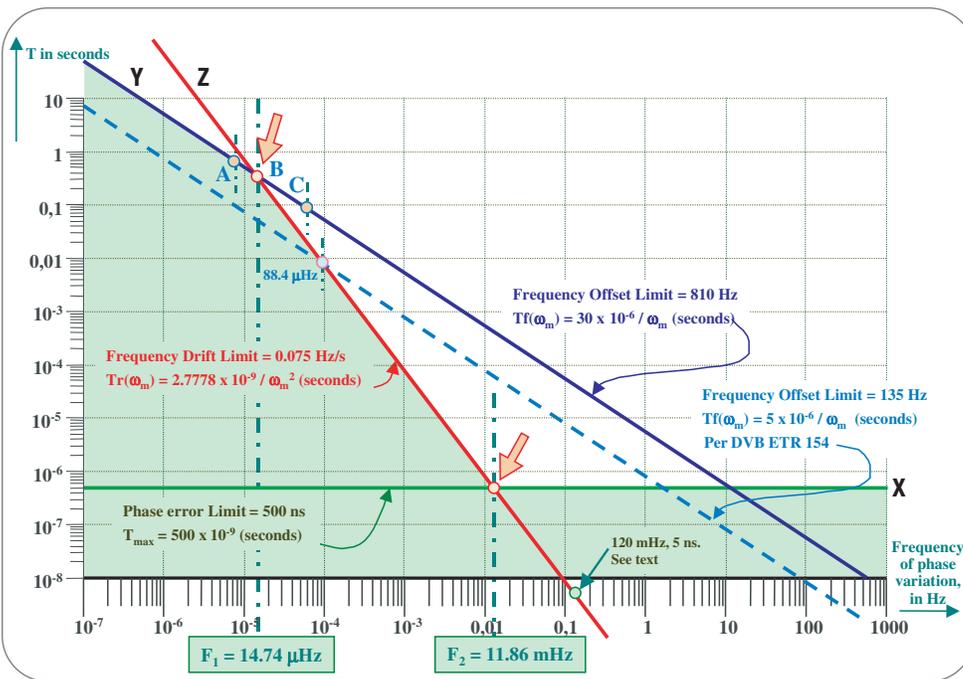
► Primer

The **drift-rate equation** becomes:

$$(7a) \text{Tr}(\omega_m) = \Phi_p / (2\pi \times 27 \times 10^6) = (2\pi \times 0.075) / (2\pi \times 27 \times 10^6 \times \omega_m^2) \\ = (2.7778 \times 10^{-9} / \omega_m^2) \text{ seconds}$$

The three equations of phase, frequency and drift are represented respectively in X, Y and Z in Figure 8. It is clear in this double logarithmic graph, that phase is a first order equation (the flat horizontal X line), frequency is an inverse second order equation (a 1 by 1 tilted Y line), and drift-rate is an inverse third order equation (a 2 by 1 tilted Z line).

All three frequencies in Figure 6 are bounded by the  $\pm 810$  Hz limit. As seen in Figures 6 and 8, frequency A still has drift-rate margin (it does not reach the Z line). Frequency C, however, is bounded by the Y line but exceeds the Z line. So, with its amplitude of  $\pm 810$  Hz and its frequency (60  $\mu$ Hz) of four times frequency B (15  $\mu$ Hz), it does not comply with the drift limitation. Another interesting aspect of Figure 8 is the crossing point of the drift and phase equations, the frequency marked  $F_2$ . They cross at about 12 mHz, which is the ideal frequency for separating drift-rate from jitter.



► **Figure 8** – The limits mask

The examples of Figure 6 have been represented in Figure 8 as A, B and C. Assuming that B is the highest frequency that can have maximum frequency deviation of  $\pm 810$  Hz, without exceeding the drift limit, notice that it lies at the intersection of the two equations for frequency and drift as calculated in Figure 7, point  $F_1$ .

Following the previous reasoning about the amplitude of the frequency deviation in Figure 6 and following the Z line in Figure 8, when the line is above 12 mHz, it allows for very little error in the PCR values. At about 120 mHz the value would be 5 ns for the maximum error of the PCR values. (It is worthwhile to remember that the 27 MHz clock has a period of 37 ns.)

The specification allows for a phase and accuracy limit as high as  $\pm 500$  ns regardless of the limits imposed by the drift limit specification for jitter frequencies higher than an  $F_2$  of 12 mHz. That is why the members of the Measurement Group of the DVB decided to establish the  $F_2$  frequency as the most convenient demarcation for accurate measurements of jitter and drift-rate in DVB systems.

### Demarcation frequencies

From Figure 8 it is relatively easy to extract the two break frequencies of interest,  $F_1$  and  $F_2$ .

$F_1$  can be found by rearranging the equations for frequency and drift-rate (6 and 7 respectively) and solving for the value of  $\omega_m$  that provides the same peak phase error:

$$\Phi_p = (2\pi \times 810) / \omega_m \quad \text{and} \quad \Phi_p = (2\pi \times 0.075) / \omega_m^2$$

radians

$$\omega_m = (2\pi \times 0.075) / (2\pi \times 810) = 9.2592 \times 10^{-5}$$

radians/sec

$$F_1 = \omega_m / 2\pi = 14.737 \times 10^{-6} \text{ Hz}$$

(For DVB,  $F_1 = 88.419 \times 10^{-6} \text{ Hz}$ )

The break frequency  $F_1$  is too low to be of practical use. When you are measuring frequency offset, you don't want to wait several days to have an averaged result appropriate to the period of such a signal.

$F_2$  can be found by rearranging and solving the equations of phase and drift-rate (5 and 7 respectively) and solving for the value of  $\omega_m$  that has the same peak phase error:

$$\Phi_p = 84.823 \text{ radians} \quad \text{and} \quad \Phi_p = (2\pi \times 0.075) / \omega_m^2$$

radians

$$\omega_m = \sqrt{(0.4712/84.823)} = 0.074535 \text{ radians /sec}$$

$$F_2 = 0.074535 / 2\pi = 0.01186 \text{ Hz}$$

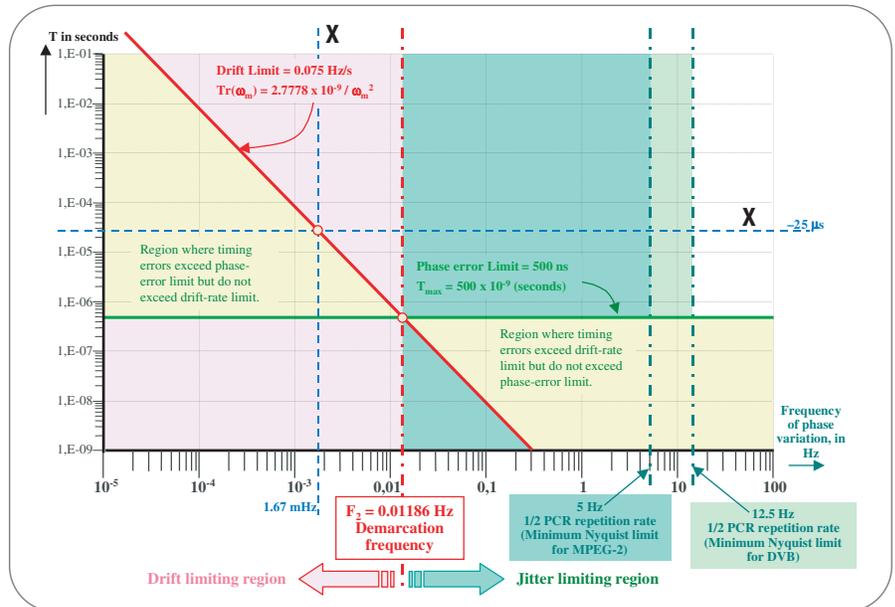
Note: The same values may be obtained by using the normalized equations 5a, 6a and 7a.

**This break frequency ( $F_2 \cong 10 \text{ mHz}$ ) is the value recommended by DVB-MG as the demarcation frequency** for separating the measurement of jitter and drift-rate. It has been defined as filter MGF1 in the corresponding table of TR 101 290. This value defines the corner frequency to be used in the filters for processing the PCR data.

A mask can be drawn from the two equations used to obtain this value (phase equation 5a and drift equation 7a), represented in Figure 9. This is a part of the graph on Figure 8, but includes only the two equations.

**Note:** For the Low Jitter Applications (ISO/IEC 13818-9), the  $\pm 25 \mu\text{s}$  limit yields a demarcation frequency of 1.67 mHz that may be used in place of the 12 mHz. This is shown in Figure 9 with the lines marked "X".

From Figure 9, note that the maximum drift of 75 mHz/s may only be reasonably applied to frequency variations that are slower than the demarcation frequency. Above that frequency it is possible in practice to find drifts much faster than the limit. Above the demarcation frequency, the limit that applies is the absolute  $\pm 500 \text{ ns}$ .



▶ **Figure 9 – The jitter-wander demarcation frequency**

### Nyquist implicit limitations

From Figure 9 it can be seen that a practical limit is also imposed on the ability to measure jitter above a certain frequency. For PCR values inserted at the minimum rate of 100 ms per ITU-T Rec.H.222.0/ ISO/IEC 13818-1, the samples arrive at the measurement instrument at 10 Hz. The Nyquist value (half the sampling rate) is consequently equal to 5 Hz.

For PCR values inserted at the minimum rate of 40 ms, per DVB ETR154, the samples arrive at the measurement instrument at 25 Hz. The Nyquist value is equal to 12.5 Hz. If higher PCR insertion rates are used in any of these environments, the corresponding Nyquist frequency increases proportionally. This implies that any statistics made by the measurement instrument based on jitter spectral analysis must take into account the actual PCR rate.

## PCR Measurements

▶ Primer

### Considerations measuring PCRs

Typical sampled system analysis relies on a regular sampling rate of the data to be analyzed. This is not generally the case for the discrete-time samples carried by PCR values which, by their nature, depend on criteria and priorities at the multiplexing stage.

None of the standards force the interval, whatever it is, to be constant. This is due to the fact that in the multiplexing process, the instant a packet is inserted into the TS may vary.

In all practical cases the sample rate will be high compared to the frequency break points of the measurement filters at 0.01 Hz—more than 1000 times higher.

For the minimum rate of PCRs (10 Hz for MPEG transport streams and 25 Hz for DVB systems), there is over-sampling, and the transient response of filters with cut-off frequencies near 0.01 Hz is not significantly affected by the uniformity of the rate.

For any practical implementation, the designer decides the best way to implement the filters: DSP techniques (digital IIR or FIR filters) with interpolation (linear,  $(\sin x)/x$ , etc.) or without interpolation, analog circuitry or hybrid technology by mixing analog and numerical analysis.

If the measurement instrument is designed as an analog device with conventional filters, then the designer will use the demarcation frequency as a requirement for the design of the filters. This demarcation frequency is derived from the limits set in the standard and does not depend on the sampling rate for the PCR values.

If the design of the filters is done by Digital Signal Processing (DSP) techniques, the designer must take into account the average sampling rate of the PCR values and adapt the filters to maintain a relatively fixed cut-off frequency for the measurement. This approach implicitly assumes that the sampling rate (average arrival rate of PCR values) is not only known, but is relatively constant.

The value of the coefficients should be determined dynamically by measuring the actual arrival rate of PCR values. In other words: use adaptive filters whose coefficients vary as a function of the measured parameter, the PCR rate. This approach has been tested in practice using very strong frequency modulation for the PCR rate. The measured jitter and drift-rate correlate closely (within the accuracy limits of the measuring device) to the jitter and drift-rate errors inserted by the test generator into the PCR values under test.

In general, small errors in the cut-off frequency of the measurement filter do not significantly affect jitter measurement results because the jitter spectral components are most often broadband. In fact, the order of the filter is most important because this determines the filter sensitivity to out-of-band components, which may have small amplitudes but very high first and second order time-derivatives.

You can apply Fourier analysis to the received sampled data as a debugging tool to find the origin of the jitter, should it exist, and have a definite periodicity or significant frequencies. For this type of analysis to be valid, it is assumed that the sampling rate is known and regular. The accuracy and frequency resolution of the analysis rely on this assumption. You can overcome problems introduced by a non-uniform sampling rate by careful interpolation before the spectral analysis is done.

In some practical cases, you may not need to do this interpolation because, as a debugging tool, there is no need to know the "exact" value of the components and their amplitudes. You only need to have an idea of whether the jitter is random (wideband) or if it has one or more predominant frequencies.

Generally, when spectral analysis is done on **regularly sampled signals**, if there is a stable sinusoidal component on the signal, its parameters can be obtained with great accuracy, and a clear spectral line can be displayed on a spectrum analyzer. If the sinusoidal component is not stable, the line becomes broader and lower in amplitude, the broadening and lowering representing the FM implicit in the signal.

When the spectral analysis is done in **non-regularly sampled signals**, for a stable sinusoid, you can expect a broad and low spectral line. For greater FM (random or not) present in the sampling rate, the spectral line becomes even broader and lower. Nonetheless, the procedure may still be valid as a diagnostic and analysis tool.

### The DVB recommended filters

For practical measurement applications, DVB-MG recommends the use of one of the following filters:

- MGF1 of 10 mHz
- MGF2 of 100 mHz
- MGF3 of 1 Hz and
- MGF4, which is user defined

This diversity of filters, rather than just the one analyzed in the previous pages, namely MGF1, best supports a test instrument that needs to be switched from one set of PCRs to another.

You may not want to wait for a filter with a cut-off frequency as low as 10 mHz to stabilize. You can obtain reasonable results with faster filters, but the numerical result will be different. Thus, provisions are made for MGF2 and MGF3.

The measurement result should be accompanied by a statement of what filter was used. Results from different test instruments should be consistent if tests are made using the same filter.

While the MGF1 filter provides the most accurate results, MGF2 offers a good compromise between measurement speed and accuracy.

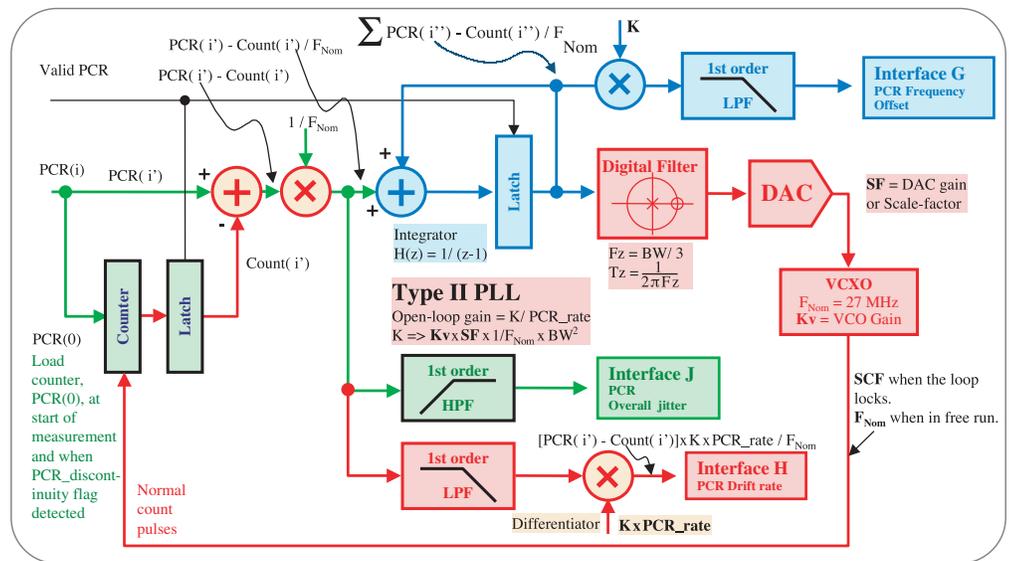
The MTM400 monitor and AD95X analysis systems from Tektronix operate with the MGF2 filter and provide PCR measurements without long waits for stabilization. Both offer PCR measurements on live streams, but also enable PCR measurements on stored streams.

The intent of the filters available in TR 101 290 is:

**MGF1 (10 mHz):** This filter gives total coverage of frequency components that may be present in the timing impairments of PCR-related values.

This profile provides the most accurate results in accordance with the limits specified in ISO/IEC 13818-1, Section 2.4.2.1.

**MGF2 (100 mHz):** This filter is intermediate between the profiles of MGF1 and MGF3 and is used by the Tektronix MTM400 monitor and AD95X analysis systems. It gives reasonable measurement response as well as reasonable measurement of the low frequency components of timing impairments.



▶ Figure 10 – A conceptual block diagram for the three measurements

Compared to MGF1, and assuming wideband jitter, this filter will provide a measurement result with less jitter and higher drift-rate. The reason is that the jitter components between 10 mHz and 100 mHz will be measured as if they were fast drift rather than slow jitter (Figure 9). If you use this filter for logging results, you should indicate that you used MGF2.

## PCR Measurements

### ▶ Primer

**MGF3 (1 Hz):** This filter provides faster measurement response by taking into account only the highest frequency components of the timing impairments. This profile should be sufficiently accurate in many applications.

Compared to MGF1, and assuming wideband jitter, this filter will produce a measurement result with even less jitter and much higher drift-rate. The reason is that jitter components between 10 mHz and 1 Hz will be measured as if they were fast drift, rather than slow jitter (Figure 9).

As the cut-off frequency of the filter is two orders of magnitude higher than the MGF1, it will also be two orders of magnitude faster; in fact, its settling time is:

$$1/\text{cut-off frequency} = 1 \text{ second.}$$

If you use this filter for logging results, you should indicate that you used the MGF3 filter.

**MGF4 (User Defined):** This filter, when available in a measurement instrument, will provide any benefit that the user may consider useful. The demarcation frequency (cut-off) has to be supplied with the measurement result. Optionally, any other data that the manufacturer or the user may consider to be relevant may be supplied.

As an example, for testing against ISO/IEC13818-9 ( $\pm 25 \mu\text{s}$  jitter limit), a demarcation frequency of 2 mHz is recommended. A filter for such a demarcation frequency may be implemented under this MGF4 profile.

Figure 10 shows a conceptual diagram valid for the measurement of the three parameters: frequency offset (PCR\_FO), the drift-rate (PCR\_DR) and the overall jitter (PCR\_OJ).

All the filters in this diagram have their frequency cut-off corresponding to one of the demarcation frequency values given by the profiles MGF1 through MGF4.

## New measurement probes

In addition to the changes of dividing in a more comprehensive way some of the parameters of the three classical priorities, DVB-MG has defined new measurement probes to test the PCR of the programs contained in any TS as follows:

### *Program Clock Reference - Frequency Offset*

PCR\_FO is defined as the difference between the program clock frequency and the nominal clock frequency (measured against a reference which is neither PCR-derived, nor TS-derived).

The parameter PCR\_FO should be expressed in **Hz** calculated as:

Measured Frequency – Nominal Frequency,

or in **ppm** calculated as:

$[\text{Measured Frequency (in Hz)} - \text{Nominal Frequency (in Hz)}] / \text{Nominal Frequency (in MHz)}$ .

The tolerance as specified by ISO/IEC 13818-1 is  $\pm 810 \text{ Hz}$  or  $\pm 30 \text{ ppm}$ .

### *Program Clock Reference – Drift-Rate*

PCR\_DR is defined as the first derivative of the frequency and is measured on the low frequency components of the difference between the program clock frequency and the nominal clock frequency (measured against a reference which is not derived from either the PCR or the TS).

The parameter PCR\_DR should be expressed in **mHz/sec (@ 27 MHz)** or **ppm/hour**.

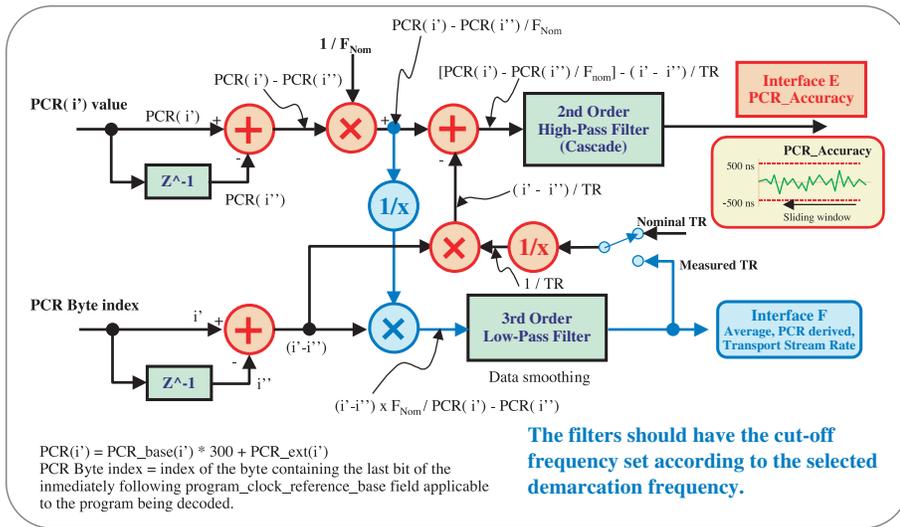
The tolerance specified by ISO/IEC 13818-1 is  $\pm 75 \text{ mHz/sec @ 27 MHz}$  or  $\pm 10 \text{ ppm/hour}$ .

### *Program Clock Reference - Overall Jitter*

PCR\_OJ is defined as the instantaneous measurement of the high frequency components of the difference between when a PCR should have arrived at a measurement point (based upon previous PCR values, its own value and a reference which is not PCR or TS derived) and when the PCR did arrive.

The parameter PCR\_OJ should be expressed in **nanoseconds**.

This value can be compared against the maximum error specification in ISO/IEC 13818-1 for PCR accuracy of  $\pm 500 \text{ nanoseconds}$  only if the jitter in the transmission is assumed to be zero.



▶ **Figure 11** – A conceptual block diagram for the PCR accuracy measurement

**Program Clock Reference – Accuracy**

The accuracy of the PCR values, PCR\_AC, is defined as the difference between the actual PCR value and the value it should have in the TS represented by the byte index for its actual position. This can be calculated for constant bit rate transport streams. The measurement may NOT produce meaningful results in variable bit rate transport streams.

The parameter PCR\_AC should be expressed in **nanoseconds**.

This measurement is designed to indicate the total error included in the PCR value with respect to its position in the TS.

The tolerance specified by ISO/IEC 13818-1 is ± 500 ns.

This measurement is considered to be valid for both real-time and off-line measurements.

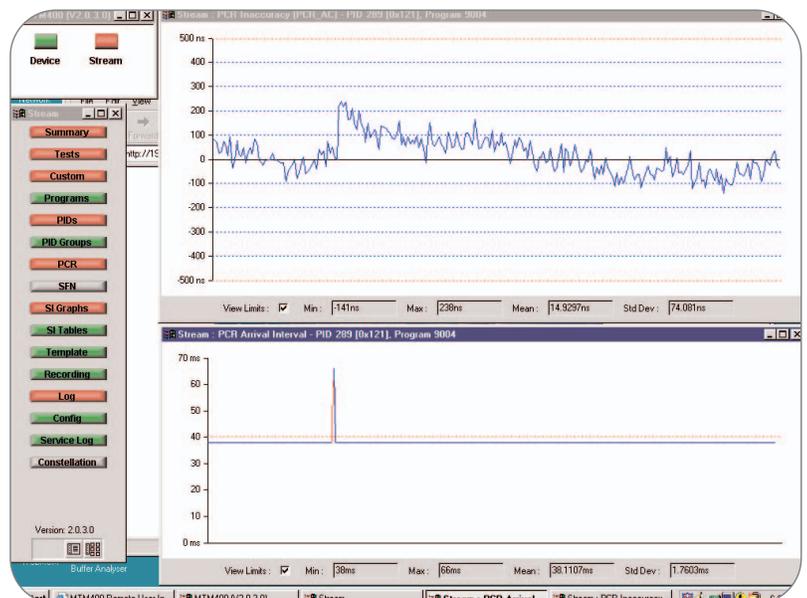
Figure 11 shows a conceptual diagram valid for the measurement of PCR accuracy. This diagram is also valid for averaged TS rate measurement.

**Measuring instruments**

Instruments that feature the new jitter measurements include the Tektronix MTM400 monitor and AD95X analysis systems.

In Figure 12, taken from a Tektronix MTM400, the lower graph indicates that the PCRs arrive at an interval close to the recommended pace of 40 ms. However, one interval exceeds the DVB limit with an interval between PCRs of 66 ms. The upper graph shows that PCR\_AC is well within the limits of ± 500 ns. Note that Mean and Standard Deviation figures for PCR\_AC are also provided.

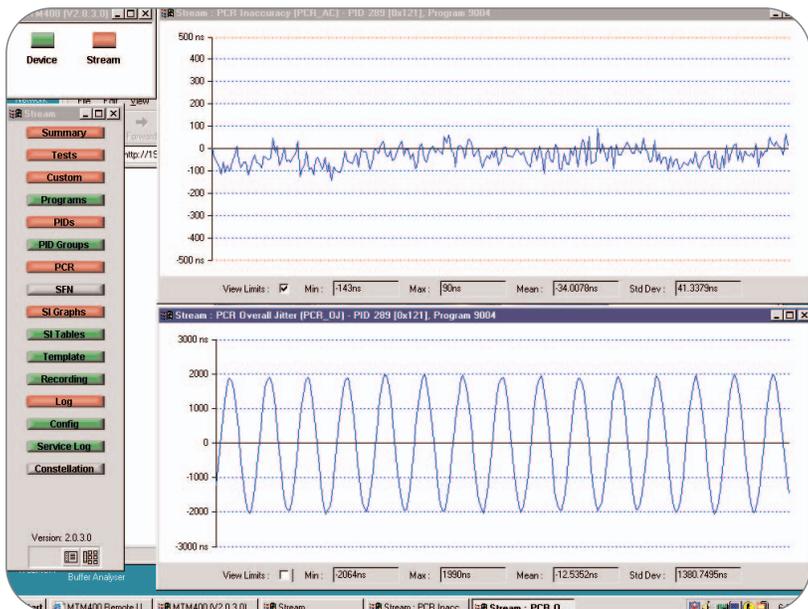
A summary of maximum and minimum values is at lower right.



▶ **Figure 12** – PCR\_AC and interval measurement results

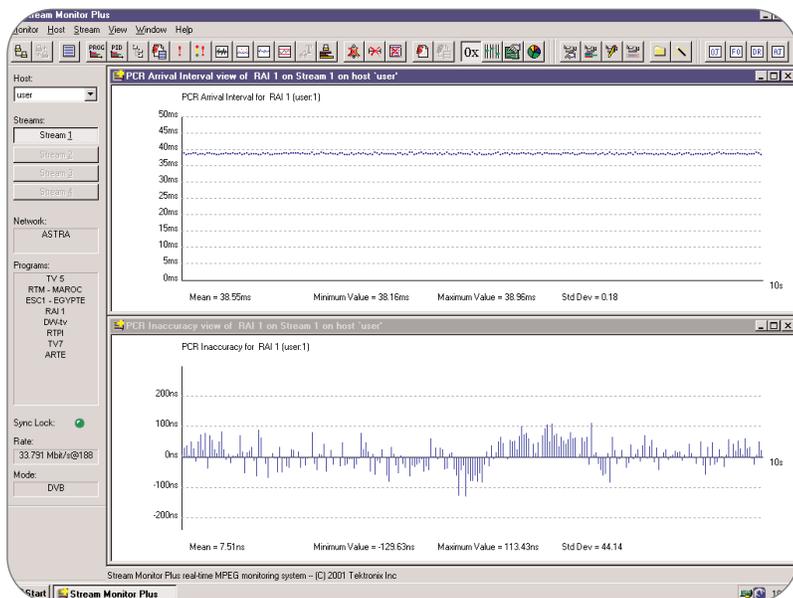
# PCR Measurements

► Primer



► **Figure 13** – PCR\_AC and PCR\_OJ measurement results

In Figure 13, again from an MTM400, PCR\_AC is shown in the upper screen and varies between -140 and +90 ns. Note that the overall jitter, PCR\_OJ, shown in the lower graph is an order of magnitude higher with max and min values of approximately 2000 ns.



► **Figure 14a** – PCR interval and PCR\_AC measurement results

Figure 14a shows PCR interval and PCR\_AC measurement results taken from the AD95X analysis system. Both measurements are within DVB limits.

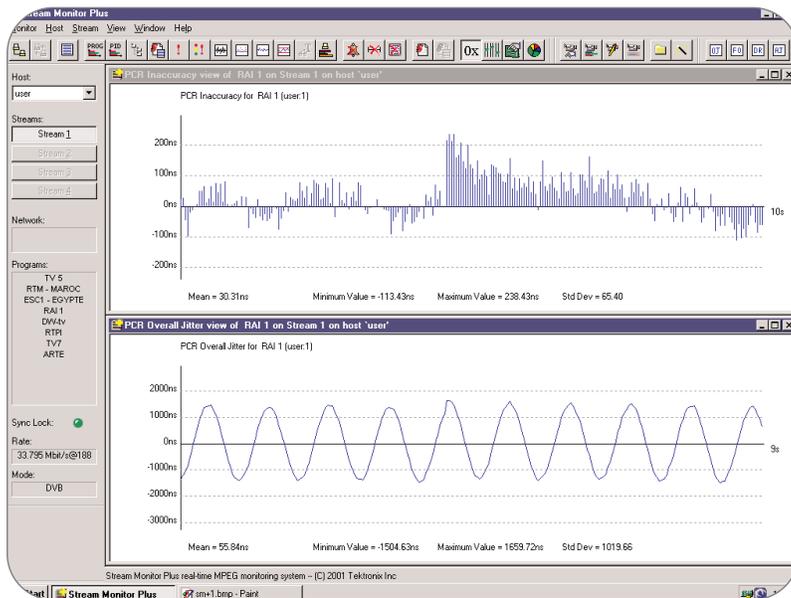
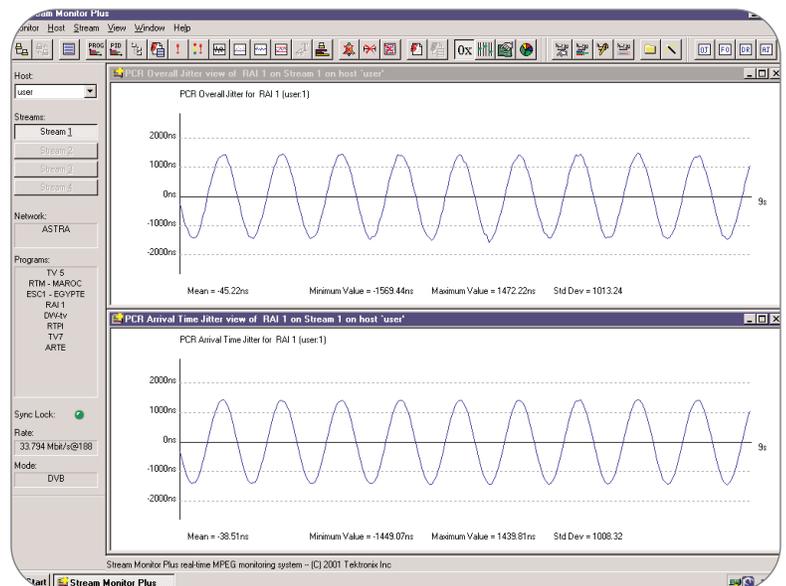


Figure 14b provides a second example of PCR\_AC and PCR\_OJ measurements, this time from an AD95X analysis system. Again, overall jitter is substantially larger.

► **Figure 14b** – PCR\_AC and PCR\_OJ measurement results



► **Figure 15** – PCR\_OJ and arrival time measurement results

PCR\_OJ always includes PCR\_AC. Subtraction of the two provides an additional measurement which may be referred to as PCR arrival time as shown in Figure 15. This represents network induced jitter and excludes any PCR\_AC errors. In general, PCR\_AC will be substantially lower than PCR\_OJ and can therefore be ignored, but where the two are similar, PCR arrival time jitter measurement provides a useful additional capability.

## PCR Measurements

▶ Primer

### Conclusions

There are drastic differences between TV synchronization systems, analog and digital, on one side and multiplexed and compressed distribution systems designed to transmit several programs sharing a common transport system, the TS, on the other side. In the latter case, synchronization is managed by sending numerical fields with the synchronization information (PCR), while in previous systems it is accomplished with electrical pulses.

There is a need for finding an appropriate demarcation frequency between jitter and wander, and we have shown how the Measurement Group of the DVB (DVB-MG) has approved the frequency of 10 mHz and has defined a mask that includes the three limits defined by MPEG-2 (ISO/IEC 13818-1): frequency offset, drift-rate and jitter (PCR tolerance). The DVB MG defines a particular filter (MGF1) for the highest accuracy measurements. Practical considerations for general measurement and monitoring applications suggest use of additional filters, one of which, MGF2 provides an ideal compromise between accuracy and speed of measurement.

Based on those definitions and filters, the DVB-MG has added new probes to the existing list of probes, including:

PCR\_FO

PCR\_DR

PCR\_OJ

PCR\_AC

The DVB-MG has also expanded the detail on the criteria used by some of the existing probes according to the three priorities.

Monitoring and analysis equipment available from Tektronix, such as the MTM400 and AD95X provide PCR measurements to TR 101 290 as defined within the DVB MG.

The appendix contains a graphical summary that defines the limits that apply to transport streams that are compliant with the MPEG-2 standard.

### Appendix: Meaning of some MPEG-2 formulas:

#### *ISO/IEC 13818-1 (1996) Section 2.4.2.1*

This section includes two tolerance values used in this article:

27MHz  $\pm$  810 Hz

Frequency tolerance =  $\pm$  30 ppm

Rate of change of SCF  $\leq$  75 x 10<sup>-3</sup> Hz /sec

Drift-rate tolerance =  $\pm$  2.7778 x 10<sup>-9</sup>/sec @ 1 Hz

The bit rates defined in this specification are measured in terms of SCF. The tolerances may then be expressed as SCF counts as follows (these values are used in the ISO/IEC 13818-4 [section 2.6.1.3] specification to define  $\delta$ ):

Frequency tolerance =  $\pm$  810 clock pulses/sec

Drift-rate tolerance =  $\pm$  75 x 10<sup>-3</sup> clock pulses/sec<sup>2</sup>

#### *ISO/IEC 13818-1 (1996) Section 2.4.2.2*

This section defines how the PCR values are calculated:

PCR(i) = PCR\_base(i) x 300 + PCR\_ext(i)

PCR\_base(i) = [(system\_clock\_frequency x t(i)) DIV 300] MOD 2<sup>33</sup>

PCR\_extension = [(system\_clock\_frequency x t(i)) DIV 1] MOD 300

A formula is included in ISO/IEC 13818-1 (1996) to calculate the individual arrival time for each byte (with index i) of a TS based on knowledge of the TS rate and the SCF. These two values can be measured using the diagrams indicated in Figures 11 and 10, respectively. A graphical representation of this arrival time formula is shown in Figure 16. It also includes a formula (shown in Figure 17) to calculate the TS rate based on the PCR values, byte indexes and the SCF. This formula is used in Figure 11 for the averaged TS rate measurement. The third limit used in this article is also defined in this section:

Phase tolerance =  $\pm$  500 ns

Phase tolerance =  $\pm$  13.5 clock pulses



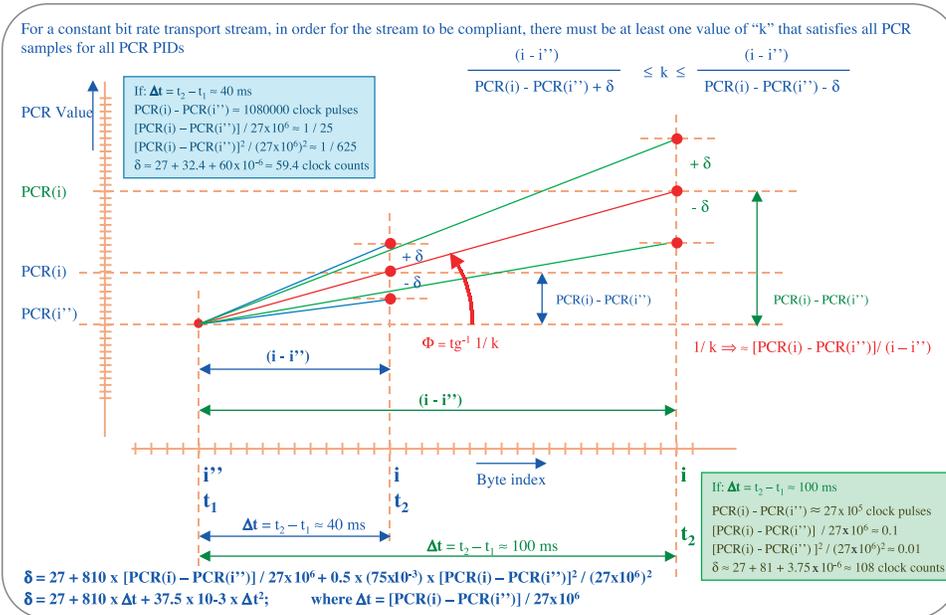
# PCR Measurements

► Primer

## ISO/IEC 13818-4 (1996) Section 2.6.1.3.

This section of ISO/IEC 13818-4 (1996) indicates the tests that may be done for verifying the PCR timing accuracy. It applies to constant bit rate transport streams that in order to be compliant, there must be at least one value of "k" that satisfies all PCR samples for all PCR PIDs in the TS per the expression in Figure 18:

The test of timing accuracy is based on the three limits of frequency offset, drift-rate and jitter. They are represented in one inequality, shown graphically in Figure 18.



► **Figure 18** – Tests on timing accuracy for constant bit rate streams

The inequality can be modified as follows:

$$(i - i'') / [\text{PCR}(i) - \text{PCR}(i'') + \delta] \leq k \leq (i - i'') / [\text{PCR}(i) - \text{PCR}(i'') - \delta]$$

$$[\text{PCR}(i) - \text{PCR}(i'')] / (i - i'') + \delta / (i - i'') \geq 1 / k \geq$$

$$[\text{PCR}(i) - \text{PCR}(i'')] / (i - i'') - \delta / (i - i'')$$

Using the formula from Figure 17:

$$[\text{PCR}(i) - \text{PCR}(i'')] / (i - i'') = \text{SCF} / \text{TS\_rate}$$

$$\text{SCF} / \text{TS\_rate} + \delta / (i - i'') \geq 1 / k \geq \text{SCF} / \text{TS\_rate} - \delta / (i - i'')$$

Multiplying by  $(i - i'') / \text{SCF}$  gives:

$$(i - i'') / \text{TS\_rate} + \delta / \text{SCF} \geq (i - i'') / k \times \text{SCF} \geq (i - i'') / \text{TS\_rate} - \delta / \text{SCF}$$

$$\text{SCF} + \delta / \text{SCF} \geq [(i - i'') / k \times \text{SCF}] - [(i - i'') / \text{TS\_rate}] \geq - \delta / \text{SCF}$$

Expressed in this form, the inequality can be seen as a bounded expression with upper and lower limits set by  $\pm \delta / \text{SCF}$ .

The central part of the expression indicates that for a TS to be compliant, a "k" value should be found such that for any PCR byte interval  $(i - i'')$ , the result measured against the TS\_rate and measured against the SCF, adjusted by "k", is such that the difference between both results is bounded by  $\pm \delta / \text{SCF}$ .

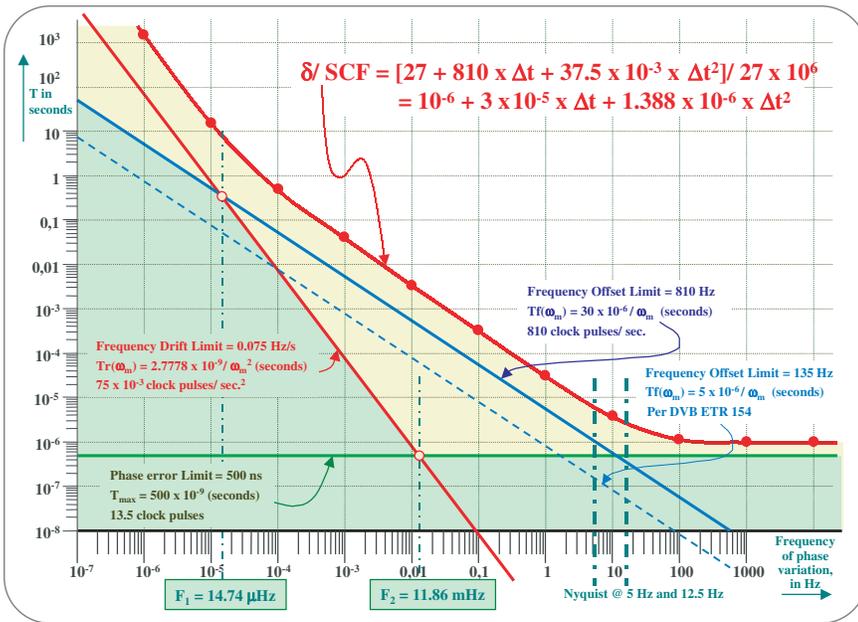
$\delta$  is defined as:

$$\delta = 27 + 810 \times [\text{PCR}(i) - \text{PCR}(i'')] / 27 \times 10^6 + 0.5 \times 75 \times 10^{-3} \times [\text{PCR}(i) - \text{PCR}(i'')]^2 / (27 \times 10^6)^2$$

$$\text{If } \Delta t = [\text{PCR}(i) - \text{PCR}(i'')] / 27 \times 10^6$$

$$\delta = 27 + 810 \times \Delta t + 0.5 \times 75 \times 10^{-3} \times \Delta t^2$$

$$\delta / \text{SCF} = 10^{-6} + 3 \times 10^{-5} \times \Delta t + 1.3888 \times 10^{-9} \times \Delta t^2$$



▶ **Figure 19** – Limit mask derived from ISO/IEC 13818-4 (1996) Section 2.6.1.3

Figure 19 shows the limit mask compared to the limits developed by the DVB-MG in Figure 8.

The limits set forth in ISO/IEC 13818-4 (1996) are less stringent than the mask developed by DVB.

In the mask defined by  $\pm\delta/SCF$ , the frequency offset limit is the predominant limit for the frequencies of interest, and is the least stringent of the three limits.

Consider also that the Nyquist frequencies of 5 Hz and 12.5 Hz typically limit the application of the phase limit set as 27 clock counts in the  $\delta$  formula of ISO/IEC 13818-4 [section 2.6.1.3].

Figure 20 shows that the limit mask will fit the 500 ns limit better if 13.5 clock counts are used in the formula defining  $\delta$ , instead of 27 counts. Also  $75 \times 10^{-3}$  is used instead of  $0.5 \times 75 \times 10^{-3}$ , as in the original formula.

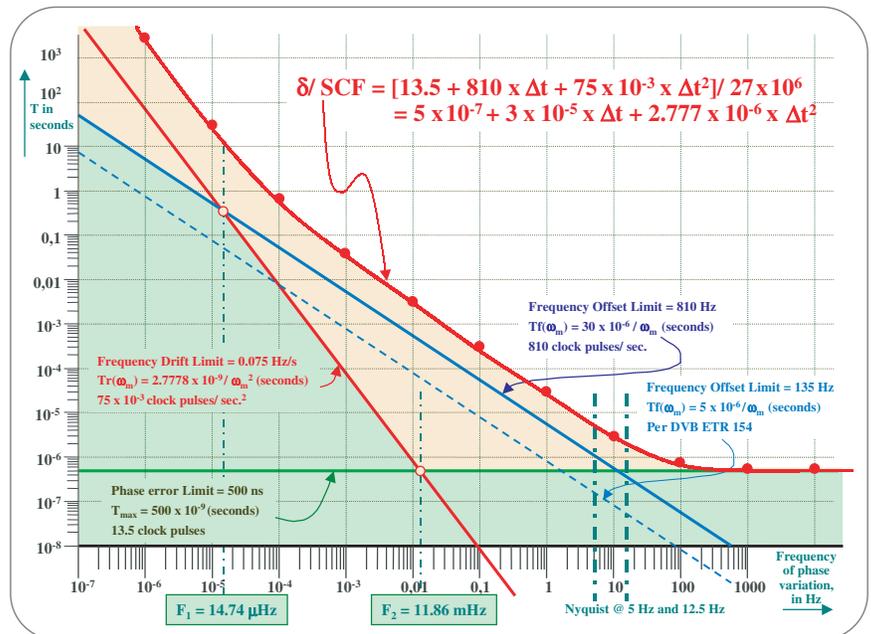
A better fit to the normalized equations used to define the DVB mask is obtained by defining  $\Delta t$  as scaled by dividing by  $2\pi$  as indicated below and in Figure 21:

$$\Delta t = [\text{PCR}(i) - \text{PCR}(i'')] / (2\pi) \times 27 \times 10^6$$

Then  $\delta$  would be defined as:

$$\delta = 13.5 + 810 \times [\text{PCR}(i) - \text{PCR}(i'')] / 2\pi \times 27 \times 10^6 + 75 \times 10^{-3} \times [\text{PCR}(i) - \text{PCR}(i'')]^2 / (2\pi \times 27 \times 10^6)^2$$

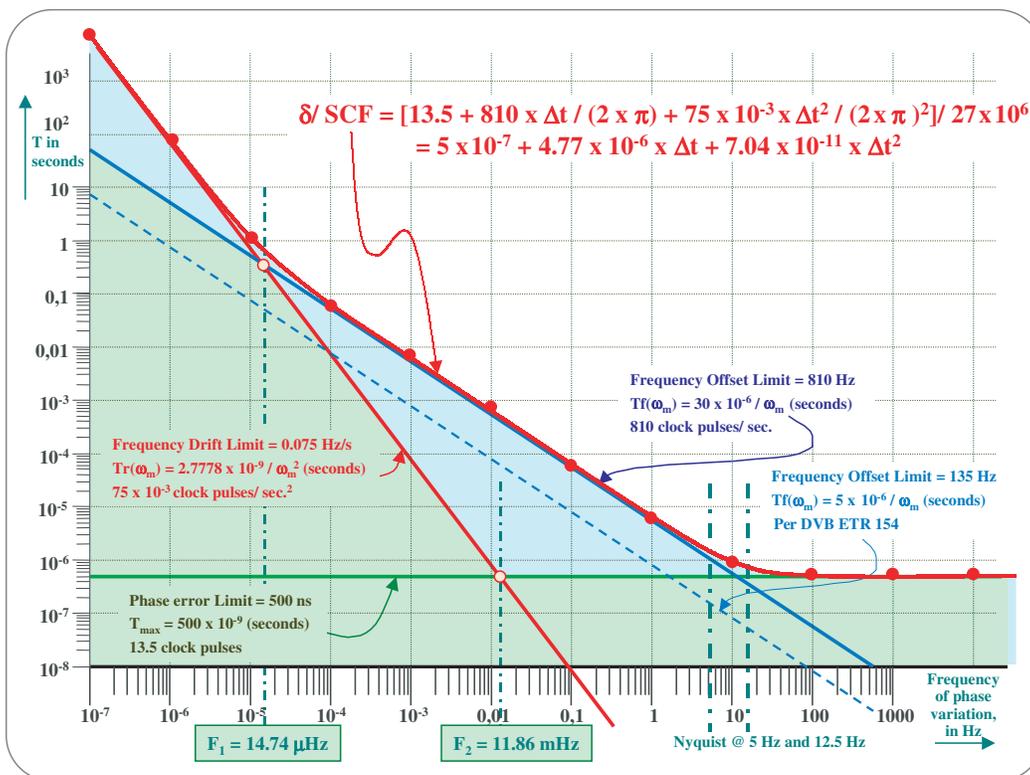
Even including the above-indicated modifications to the definition of  $\delta$ , the resulting mask is more permissive than the one developed by the DVB-MG.



▶ **Figure 20** – Limit mask from ISO/IEC 13818-4 modified using clock counts

# PCR Measurements

► Primer



► **Figure 21** – Limit mask from ISO/IEC 13818-4 multiplying  $\Delta t$  by  $1/2\pi$

Notice the big area of jitter allowance between 100 mHz and 10 Hz, where the limiting factor is only the frequency offset rather than the drift-rate or the phase limits. At 10 mHz the difference in jitter allowance is as much as 1000 times greater.

The methods developed by the Measurement Group of the DVB, described in the main body of this article, can be applied to live transport streams. They are not just theoretical, since there are already practical implementations in use.

## ISO/IEC 13818-9 (1996) Section 2.5.

This part of the standard recommends that for Real-Time-Interface for Low Jitter Applications, the maximum jitter should be less than  $\pm 25 \mu\text{s}$ .

Low jitter applications tolerance =  $\pm 25 \mu\text{s}$ .

This value has been taken into account in the mask of Figure 9.

Sections 3.2 and 3.3 describe procedures for compliance testing that may be done off-line.

**Acronyms and abbreviations used**

@	at	μHz	micro Hertz
AC	Accuracy (MG)	MPEG	Moving Picture Expert Group
ASI	Asynchronous Serial Interface	MTM	MPEG Transport Monitoring (Tektronix)
ATM	Asynchronous Transfer Mode	NTSC	National Television System Committee
BT	Broadcast Television (Series of Recommendations by ITU)	OJ	Overall Jitter (MG)
CCIR	Comité Consultatif Internationale de Radiocommunications (ITU-R)	PAL	Phase Alternating Lines (TV)
CI	Common Interface (DVB)	PCR	Program Clock Reference (MPEG)
DR	Drift Rate (MG)	PDH	Plesiochronous Digital Hierarchy
DSP	Digital Signal Processing	PES	Packetized Elementary Streams (MPEG)
DVB	Digital Video Broadcasting	ppm	parts per million (10E-6)
EBU	European Broadcasting Union	PS	Program Stream (MPEG)
ETR	ETSI Technical Recommendation	PSN	Packet Switched Networks
ETSI	European Telecommunications Standards Institute	PTS	Presentation Time Stamp (MPEG)
FIR	Finite Impulse Response (digital filters)	RP	Recommended Practice (SMPTE)
FM	Frequency Modulation	SCH	Subcarrier-Horizontal (TV)
FO	Frequency Offset (MG)	SCR	System Clock Reference (MPEG)
GOP	Group Of Pictures (MPEG)	SDH	Synchronous Digital Hierarchy
Hz	Hertz	SECAM	Sequential Couleur A'Memoire
IEC	International Electro-technical Commission	SMPTE	Society of Motion Picture and Television Engineers
IIR	Infinite Impulse Response (digital filters)	SONET	Synchronous Optical Network
ISO	International Organization for Standardization	STD	System Target Decoder (MPEG)
ITU-R	International Telecommunications Union - Section Radio-Communications	TR	Technical Recommendation (ETSI)
ITU-T	International Telecommunications Union - Section Tele-Communications	TS	Transport Stream (MPEG)
MG	Measurement Group (DVB)	T-STD	Transport Stream - System Target Decoder (MPEG)
MGF	Measurement Group Filter (DVB)	TV	Television
MHz	Mega Hertz	UER	Unión Europea de Radiocomunicaciones
mHz	milli Hertz		

**Contact Tektronix:**

**ASEAN / Australasia / Pakistan** (65) 6356 3900

**Austria** +43 2236 8092 262

**Belgium** +32 (2) 715 89 70

**Brazil & South America** 55 (11) 3741-8360

**Canada** 1 (800) 661-5625

**Central Europe & Greece** +43 2236 8092 301

**Denmark** +45 44 850 700

**Finland** +358 (9) 4783 400

**France & North Africa** +33 (0) 1 69 86 80 34

**Germany** +49 (221) 94 77 400

**Hong Kong** (852) 2585-6688

**India** (91) 80-2275577

**Italy** +39 (02) 25086 1

**Japan** 81 (3) 3448-3010

**Mexico, Central America & Caribbean** 52 (55) 56666-333

**The Netherlands** +31 (0) 23 569 5555

**Norway** +47 22 07 07 00

**People's Republic of China** 86 (10) 6235 1230

**Poland** +48 (0) 22 521 53 40

**Republic of Korea** 82 (2) 528-5299

**Russia, CIS & The Baltics** +358 (9) 4783 400

**South Africa** +27 11 254 8360

**Spain** +34 (91) 372 6055

**Sweden** +46 8 477 6503/4

**Taiwan** 886 (2) 2722-9622

**United Kingdom & Eire** +44 (0) 1344 392400

**USA** 1 (800) 426-2200

**USA (Export Sales)** 1 (503) 627-1916

For other areas contact Tektronix, Inc. at: 1 (503) 627-7111

Updated 20 September 2002

**For Further Information**

Tektronix maintains a comprehensive, constantly expanding collection of application notes, technical briefs and other resources to help engineers working on the cutting edge of technology. Please visit [www.tektronix.com](http://www.tektronix.com)



Copyright © 2003, Tektronix, Inc. All rights reserved. Tektronix products are covered by U.S. and foreign patents, issued and pending. Information in this publication supersedes that in all previously published material. Specification and price change privileges reserved. TEKTRONIX and TEK are registered trademarks of Tektronix, Inc. All other trade names referenced are the service marks, trademarks or registered trademarks of their respective companies.

05/03 FL5630/WWW

25W-14617-1

