CLOCK RECOVERY IN THE GIGABIT REGION USING DIELECTRIC RESONATORS AS AN ALTERNATIVE TO SURFACE ACOUSTIC WAVE FILTERS

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ABSTRACT

The characteristics of coaxial dielectric resonators pertinent to clock recovery are evaluated and shown to compare favorably with surface acoustic wave filters. A practical circuit implementation of a dielectric resonator-based clock recovery system at 1.152 Gb/s demonstrates the potential of this technology for gigabit fiber optic transmission systems.

INTRODUCTION

In recent years the recovery of clock from digital data streams in the tens of hundreds of megahertz range has been effectively implemented using surface acoustic wave (SAW) filter technology. Once engineered, a SAW filter is a mass-producible high-performance stable device. However, as data rates extend into the gigahertz region, lithographic techniques used to fabricate SAW filters reach a technology limit, making SAW filters difficult to obtain, particularly as system engineers strive for transmission rates beyond 2 Gb/s.

As an alternative to the SAW filter, the maturing technology of dielectric ceramics can be effectively applied in gigabit clock recovery applications. Dielectric resonators made from this material are practical from a few hundred megahertz to many gigahertz, have low loss and are stable (1). This paper shows that dielectric resonators compare favorably to SAW filters for clock recovery and data regeneration systems at 1.152 Gb/s.

PHASE STABILITY OF DIELECTRIC RESONATORS AND SAW FILTERS

To maximize signal-to-noise performance in a clock recovery system, the phase of the recovered clock at the instant of retiming is normally aligned to the center of received data's eye pattern. Changes in this phase are primarily associated with temperature, and degrade the signal-to-noise ratio. To assess phase stability, temperature tests from –20°C to +70°C were made on a dielectric resonator and SAW filter specified for use in clock recovery applications near 560 MHz. Filter characteristics and results are shown in the following table.

Filter Type	Center Frequency	Q	Insertion Loss	Group Delay	Temperature	Frequency Change	Phase Change
Coaxial Dielectric Resonator	576 MHz	212	7.3 dB	180 ns	+70°C -20°C	+87 ppm -680 ppm	+3° -25°
SAW	552 MHz	120	26 dB	595 ns	+70°C -20°C	-254 ppm +100 ppm	-30° +12°

The Q of each filter is representative of that required in a clock recovery application and will be discussed further in the next section. Insertion loss for the dielectric resonator is much smaller than that of the SAW filter, easing input-to-output isolation constraints and gain required in the post-resonator amplifier stage. The phase change over temperature for the two filters is comparable even though the change in the center frequency from a 25°C ambient is larger for the dielectric resonator. This favorable situation exists because changes in phase are linearly related to changes in center frequency by the group delay τ_D according to $\Delta\Phi = \Delta f \cdot \tau_D \cdot 360$. The smaller τ_D, the less sensitive phase delay is to center frequency instability. SAW filters typically have large group delays associated with acoustic wave progagation through the device. The phase changes calculated using this expression and shown in the table have been confirmed with phase measurements. These results indicate that dielectric resonators offer similar phase stability and smaller insertion loss than SAW filters.

1.152 G/bs CLOCK RECOVERY SYSTEM USING A DIELECTRIC RESONATOR FILTER

A clock recovery system must accommodate both phase changes in the recovered clock, as previously related to temperature, and long transitionless intervals. Tolerable phase changes can be quantified for a raised cosine approximation to the eye pattern shape, where a phase shift of 74° corresponds to a 1 dB optical power penalty in receiver sensitivity, a typical worst case budget for a single-hop system. Repeater links generally have a more stringent requirement on the tolerable phase shift, typically 6° (2). Long transitionless intervals have a finite probability of occurrence, even in telecommunications systems with data scrambling. A robust clock recovery system should tolerate intervals of 100 transitionless bits. To investigate gigabit clock recovery performance, a dielectric resonator centered at 1.152 GHz was evaluated over temperature and then inserted into the clock recovery system in Figure 1 to assess the effect of long transitionless intervals.

The coaxial dielectric resonator had a two-pole Butterworth response, Q of 212, insertion loss of 6.2 dB, group delay of 79 ns, and was fabricated into a compact structure (15×22 mm footprint). Its center frequency at 25°C changed +13 ppm at 70°C and –35 ppm at -20°C, which contributed to phase changes in the clock recovery application of +0.4° and –1.14°, respectively, well within the 6° objective of repeatered links. This phase change is much smaller than that of the 576 MHz resonator, and is attributed to a high degree of match between the temperature coefficients of the dielectic material and the dielectric constant. Though the phase stability of the 576MHz resonator limits its use to single-hop applications, the much improved stability of the 1.152 GHz resonator demonstrates the potential of temperature coefficient matching to open up applications in repeatered links.

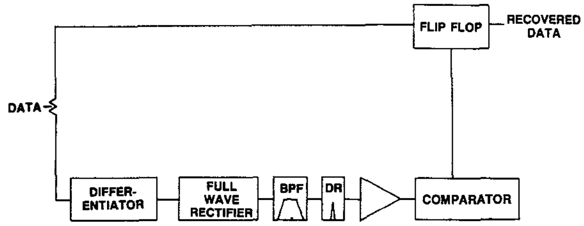

Figure 1. 1.152 Gb/s clock recovery systems using a dielectric resonator. DR is the dielectric resonator and BPF a bandpass roofing filter that suppresses spurious and higher order modes.

An additional phase change that occurs during long transitionless intervals is related to differences between the transmit clock and the resonator's center frequency. When transitions cease to exist, the filter's output will drift from the system clock frequency to its own self-resonant frequency, causing a phase shift in the clock's position every cycle of the filter's output. If one assumes the worst case of an instantaneous shift in filter output to its self-resonant frequency, the cumulative buildup in phase shift is given by $\Delta\phi = N \cdot |f_c - f_0| \cdot 1/f_0 \cdot 360$, where f_c is the system clock rate, f_0 the resonant frequency of the filter, $1/f_0$ the period of the resonance, and N the number of cycles of the resonance. This phase change is unrelated to phase error caused by detuning in combination with filter τ_D described earlier, and in fact is additive. For the the resonator temperature stability of 35 ppm, a 15 ppm budget for f_c, and N=100, the worst case phase change is $\Delta\phi = 1.8°$, well within the objective for repeatered links. When combined with the phase error caused by detuning in combination with filter τ_D, the total phase error of 3° still leaves ample safety margin for component tolerances.

The number of poles in the resonator, resonator Q, and dynamic range of the post resonator comparator also affect the length of the transitionless interval that may be tolerated. Figure 2 shows envelope decay or ringdown of the two dielectric resonators, one a single-pole design, the other a two-pole structure, during a 100-bit transitionless interval inserted into a random data sequence.

Measurement of the change in envelope amplitude as a function of number of bit periods after start of the transitionless interval have been plotted in Figure 3 for two-pole resonator having a Q of 212. Also shown are theoretical values for the one- and two-pole filters at Q of 100, 200, and 300. In specifying the number of poles and Q of the resonator, the dynamic range of the post-resonator comparator must be considered. The GaAs integrated circuit comparator could only tolerate an evelope decay of 10 dB. Even with this small dynamic range, errors in the regenerated data weren't observed until 120-bit intervals after cessation of transitions, exceeding performance objectives. Alternatively, Figure 3 indicates that a single-pole resonator having Q=300 could have achieved the 100-bit requirement.

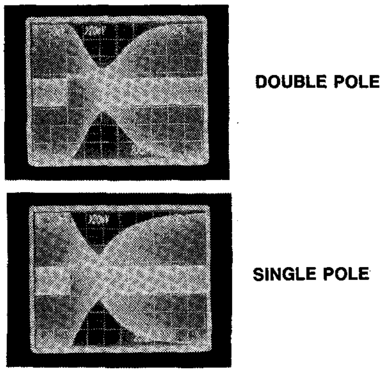

Figure 2. Photographs of enveloped decay in one- and two-pole dielectric resonators during a 100 bit transitionless interval.

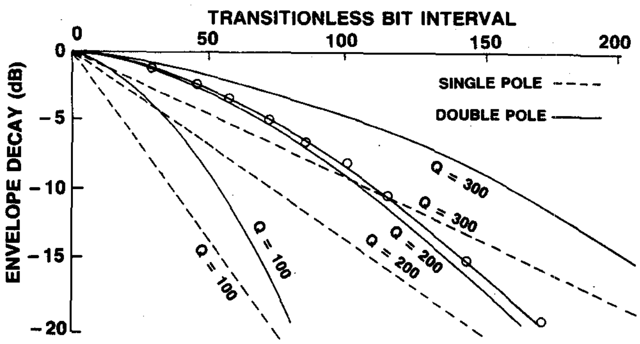

Figure 3. Dependence of resonator envelope decay on number of transitionless bit intervals, number of poles, and resonator Q. Circles denote measured data points for two-pole resonator having Q of 121.

CONCLUSIONS

Dielectric resonators were shown to be a viable alternative to SAW filters in gigabit clock recovery applications. The phase stabilities of a dielectric resonator and SAW filter, nominally designed for 560 Mb/s applications, were comparable over temperatures from –20°C to +70°C and more than adequate for clock recovery in single-hop fiber optic transmission systems. Highly improved phase stability was obtained in a 1.152 Gb/s dielectric resonator that matched material and dielectric constant temperature coefficients. Such resonators could be used for clock recovery in each repeater of a more demanding multihop transmission system. Implementation of a complete clock recovery system at 1.152 Gb/s using a dielectric resonator filter demonstrated tolerance to 100-bit-long transitionless intervals characteristic of robust designs. These results indicate that dielectric resonator technology is a practical alternative to the SAW filter in the 0.5 to 2 Gb/s region. As future data rates extend to beyond 2 Gb/s, where SAW filters are not readily available, the dielectric resonator becomes a prime candidate for clock recovery because of its low insertion loss, stable phase characteristics over wide temperature ranges, and realizable Q.

REFERENCES

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