I. Potential Prior Assumptions Regarding TF Behaviors

1. 18 volts/FSR. General design guideline. Offers a maximum requirement guideline over all types of TF applications.
2. 18 volts over temperature.
3. 20 volts aging – based on prior discussions/interpretations of GR-2883 test results.

Using these basic assumptions, it could be assumed that the requisite electrical drive circuitry to accommodate for all TF behaviors could be mapped out as seen in Figure 1. This apparent conclusion of –17 to 77 volts is inconsistent with the 0 – 60 volt design recommendations given by Micron Optics. The next section will explain the phenomena that bridge these apparent inconsistencies.

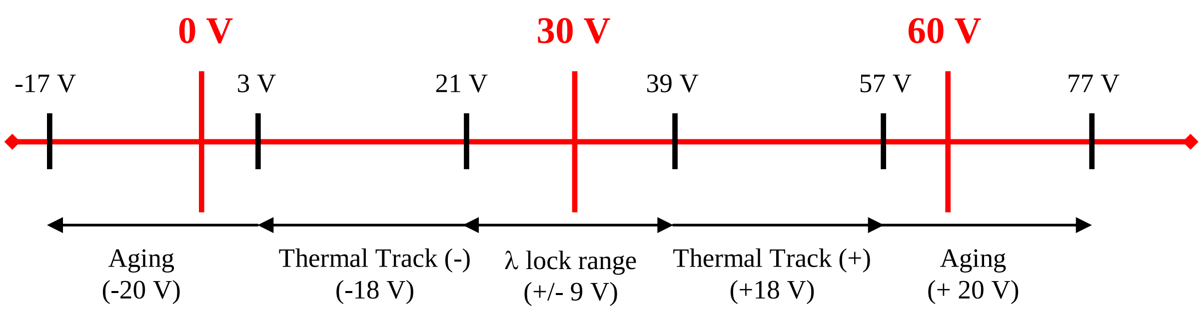

Figure 1. Conceptual design parameter map for TF2 based upon Section I assumptions.

II. Corrected Design Parameters

A. Full Scan Vs. Bias-Stepped V/FSR

The tunable filter can be used in a number of potential applications. The means by which the filter can be actuated may vary by application. In actuality, the PZT behaviors do vary as a function of these actuation methods.

Assumption 1 from Section I states that the TF Voltage per FSR is 18 volts. This is the maximum voltage for a single optical order tuning across all applications and actuation conditions, but is not a constant over all condition. Refer to Figure 2.

The pink (square) datapoints in Figure 2 show the Volts/FSR versus the voltage at which resonance peaks are found. The tuning voltage for this series of filters consists of a full 0 to 60 volt triangle wave. This is the method by which MOI tunable filters are built and qualified. It can be seen that independent of the voltage at which resonance modes are detected, the relative voltage between two modes is consistent and ~ 16 to 18 volts.

Contrast this data with the dark blue (diamond) datapoints and associate curve fit. These datapoints were taken under the conditions where a reduced DC component of ~18 volts is applied to the filter, and an added DC component allows the filter to scan varying voltage ranges. Under these conditions, which are more analogous to a "tracking noise filter" application, the Volts/FSR parameter varies greatly as a function of applied bias voltage.

As such, it is entirely appropriate to design actuation circuitry with the expectation that the PZT displacement efficiency will be positively affected by applied bias voltage. Use of the curve seen in Figure 2 will allow for modifications in the assumptions about TF and PZT behavior, ultimately leading to a conclusion of vastly reduced voltage requirements for TF use.

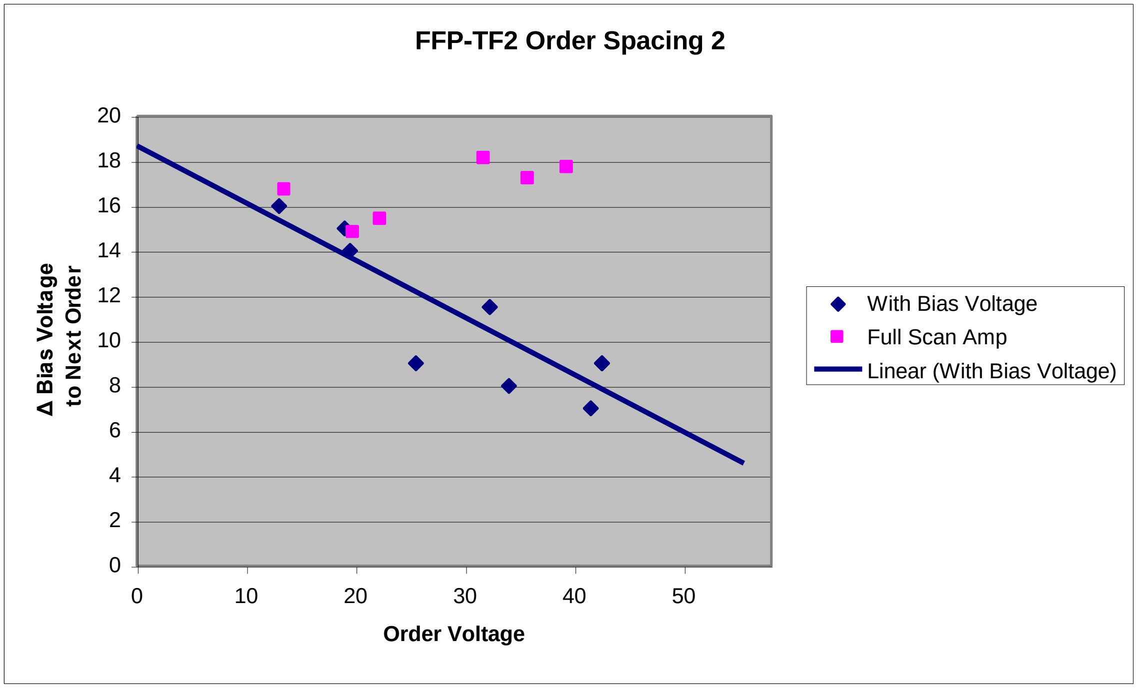

Figure 2. Using limited 18 Volt scan amplitude, Volts/FSR parameter varies strongly as a function of bias voltage applied to PZT. Driver circuit design parameters can be modified to account for these behaviors.

B. Thermal Compensation over Operating Range

Assumption 2 from Section I states that there is a design parameter of 18 volts required for thermal tracking of a completed TF2 optical filter. This assumption should be modified for a few reasons.

First, this number reflects a test limit during a Final Functional Test/Burn-in procedure at MOI. The test conditions for the FFT/Burn-in include approximately a 20 volts bias voltage on the TF and ambient temperature swings of –20 to 80° C. Since the thermal compensation is known to be nearly linear over the operating temperature range, the 18 volt limit can first be modified by the intended actual operating temperature range. For example, an operating temperature range of –5 to 65° C can be expected to require approximately 70% of the test limited voltage of 18 V, or ~ 13 Volts/70° C. Referring to Figure 2, it can be seen that with a bias voltage of 20 Volts, this value of 13 volts corresponds to almost exactly one Free Spectral Range. Thus, we can assume that the thermal tracking voltage will scale with the Δbias parameter plotted in Figure 2.

C. Annealing PZT Fixtures

Assumption 3 of Section I comes from an interpretation of the accelerated aging tests from the TF2 GR-2883 testing program. Viewing the 85°C Dry Heat testing will lead educated readers to assume that a voltage design range of 20 V must be included to accommodate for aging effects of the filter. Were it not for additional processes incorporated into the MOI manufacturing process, this assumption would be accurate. MOI has learned from the accelerated aging tests that a 250 hour annealing process for assembled fixtures will limit the migration to less than 10 volts. This process has been implemented for all MOI TF2 manufacturing, and thus, the design requirement for voltage range due to aging can be limited to +/- 10 volts.

As with the thermal tracking parameter, the aging voltage range is also a function of bias voltage. Given that the test filters for GR-2883 testing had a bias voltage offset of ~20 volts, Figure 2 shows that the 10 volt aging parameter accounts for a little less than 1 FSR. As such, the voltage needed to accommodate for aging processes will also scale with bias voltage and can be approximated with the Δbias parameter plotted in Figure 2.

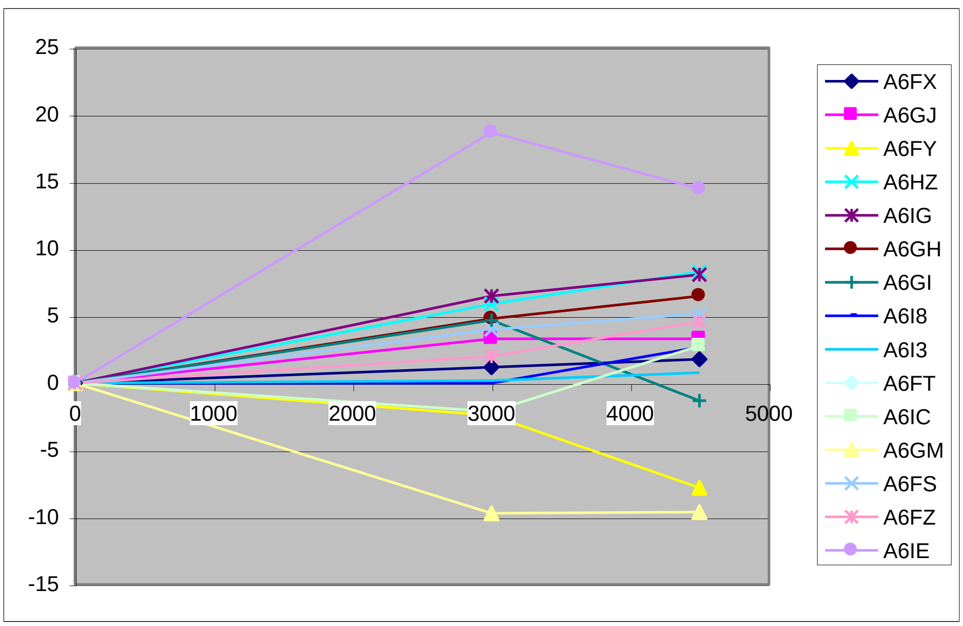

Figure 3. Accelerated Aging Offsets Normalized to post-Annealing bias values.

D. Resulting Actuator Design Map

Figure 4 below shows how the combination of the effects outline in subsections A-C can combine to yield the prescribed design targets suggested by MOI. It is important to recall that the various ranges specified below as requirements require a statistically unlikely worst-case addition of lock location and temperature, thermal compensation magnitude and direction, and TF aging to become necessary. That having been said, even these unlikely conditions can be accommodated with an available drive voltage of 0 to 56 volts, provided that the scan voltage applied to the PZT is 18 volts or less.

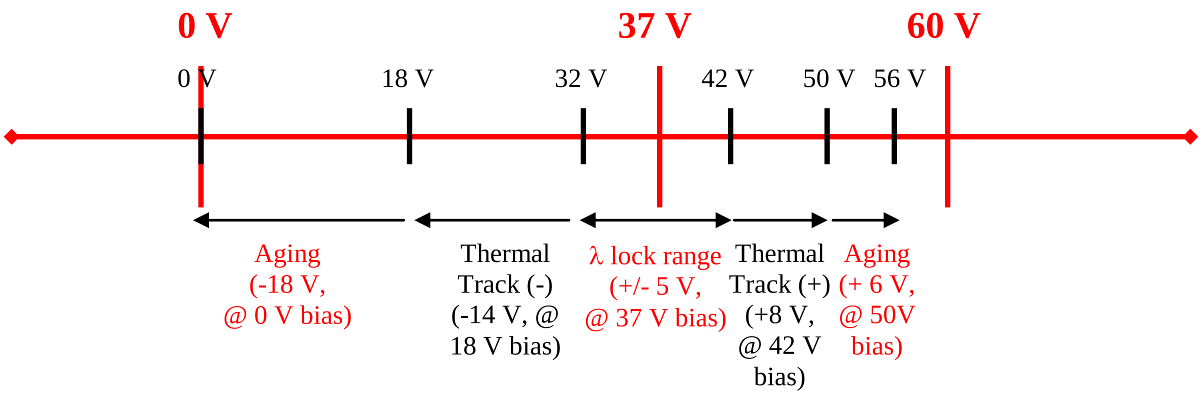

Figure 4. Modified Actuator Design Map with Design Parameter Corrections