Optical Notch Filters for Recycler Stochastic Cooling

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Abstract: *Notch filters have been constructed for the 0.5-1.0 GHz and 1.0-2.0 GHz Recycler stochastic cooling systems. Notches are placed at the core revolution orbit frequency of 89813.23 Hz. The purpose of the notch filters is to create the required transfer function for momentum cooling. The notch filters are in the MI 21 peanut.*

Notch Filter

The notch filter is a correlator, realized by splitting the signal into two separate signals. One signal travels through a long delay line, and the other travels through a short delay line. The signals are then recombined 180 degrees apart in phase. The resulting signal has notches at frequencies equal to the difference in time delay. A diagram of the correlator notch filter is shown in fig. 1.

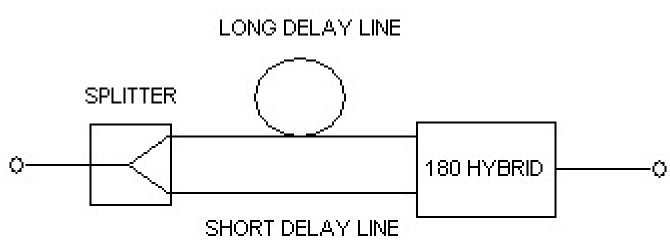

Fig.1. Correlator Notch filter

The long delay line is realized using a fiber optic link, with appoximately 2 km of Sumitomo temperature stabilized fiber optic cable on a spool. The optical transmitter, receiver, and fiber optic cable are temperature controlled to +/-0.1 degrees. The temperature control is used to keep the length of the fiber optic cable as constant as possible. A temperature change of one degree coreresponds to a change in eletrical delay of 3 ps, for a 2 km spool of fiber optic. A feedback system is also used to correct for any changes in the length of the long delay line. The feedback system is designed to keep the length of the long delay line from drifting more than +/- 3 ps. This makes the frequency of the notches stable to within 1/100 Hertz at the fundamental frequency of 89 kHz. A diagram of the notch filter, with all components, is shown in fig. 2.

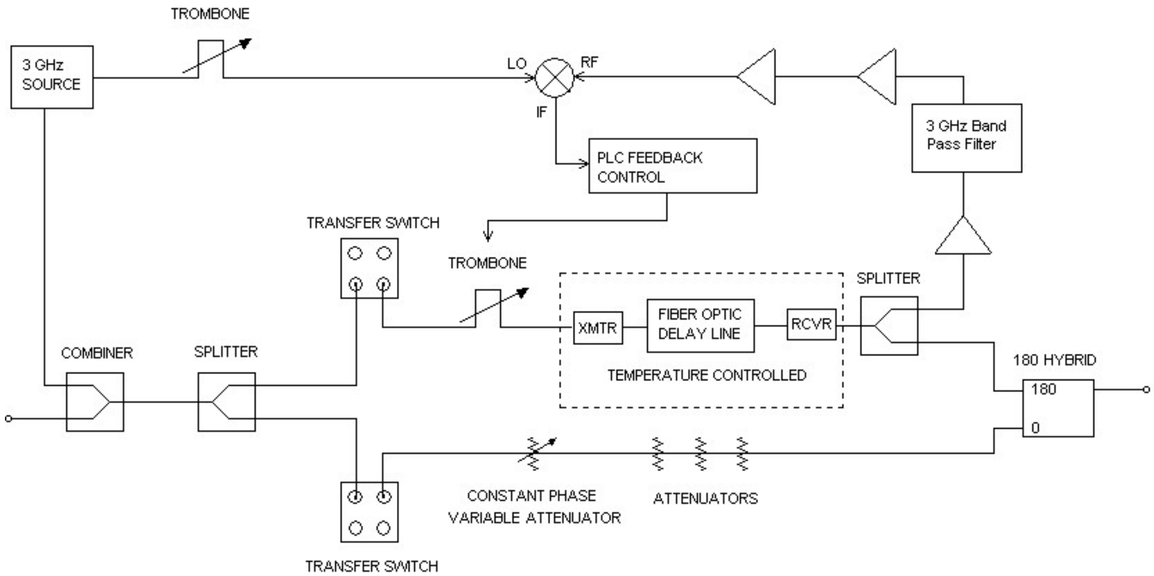

Fig. 2. Notch filter block diagram

Feedback System

A 3 GHz source is used in the feedback system to detect any changes in length of the long delay line. A change in length is detected by feeding the 3 GHz through the long delay line of the notch filter. After the 3 GHz signal passes through the long delay line, the phase is then compared to the phase of the original source using a phase detector. Any change in electrical length will result in a phase shift through the long delay line, and a DC voltage will result at the output of the phase detector. The DC voltage, or error signal, is then fed into a PLC that controls a trombone in the long delay line, correcting for a change in length.

Setting up the Filter

The notch filter must be first adjusted so that the feedback system works properly. The error voltage at the output of the phase detector must be at 0 volts when the filter has the maximum depth notches at the desired frequencies. The depth of the notches can be observed on a network analyzer by programming a list of points at the top and bottom of the notches. With the PLC control OFF, the trombone in the long leg is adjusted so that maximum depth notches is seen on the network analyzer. The trombone must also be kept close to its midpoint, otherwise changes in cable length must be made so that the trombone is close to midpoint. Once the filter has maximum depth notches at the desired frequency, the trombone at the output of the 3 GHz source is adjusted so that the error voltage at the output of the mixer is 0 volts. Once the error voltage is set to 0 volts, the PLC control is turned ON.

Measured Data

When constructing the filter, the magnitude and the phase through the long leg and the short leg are measured. It is desired that the magnitude is the same, and the phase is 180 degrees apart. Measurements of the magnitude and phase of the 0.5-1.0 GHz filter is shown in fig. 3, and measurements of the magnitude and phase of the 1.0-2.0 GHz filter is shown in fig. 4. For the 0.5-1.0 GHz filter, the electrical delay of the long leg is 11.17662447 microseconds, and the electrical delay of the short leg is 42.664 nanoseconds. This is not the real delay of the lines because the network analyzer is not calibrated and there is an unknown length of cable from the network analyzer to the filter in this measurement. The difference between the two legs is the desired information, and the difference between electrical lengths will give the notch frequency spacing.

11.17662447 us – 42.664 ns = 11.133960472 us

1 / 0.000011133960472 s = 89815.3 Hz

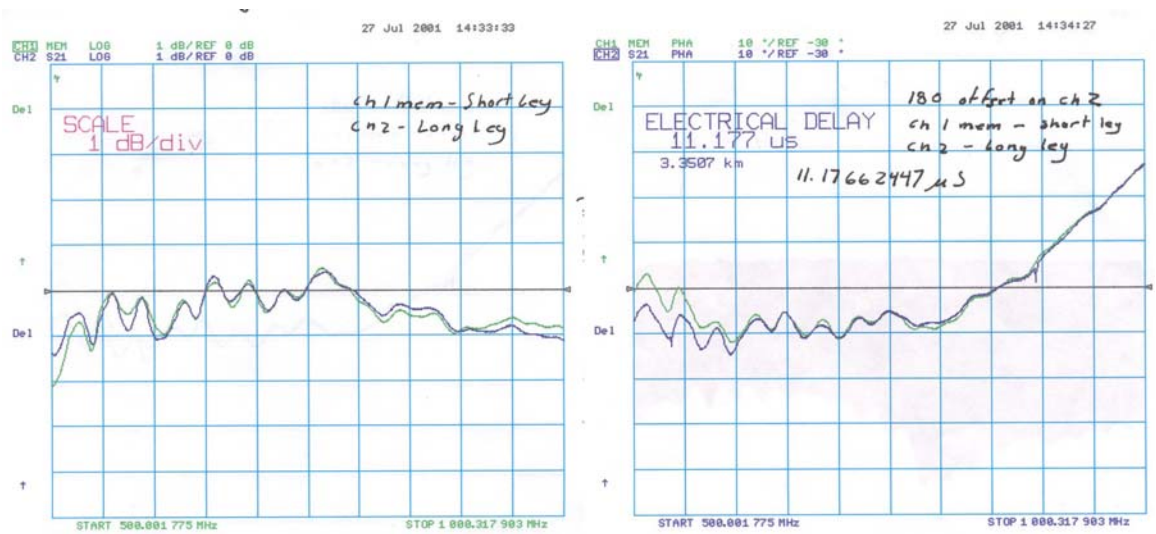

Fig. 3. Magnitude and phase of the 0.5 –1.0 GHz notch filter

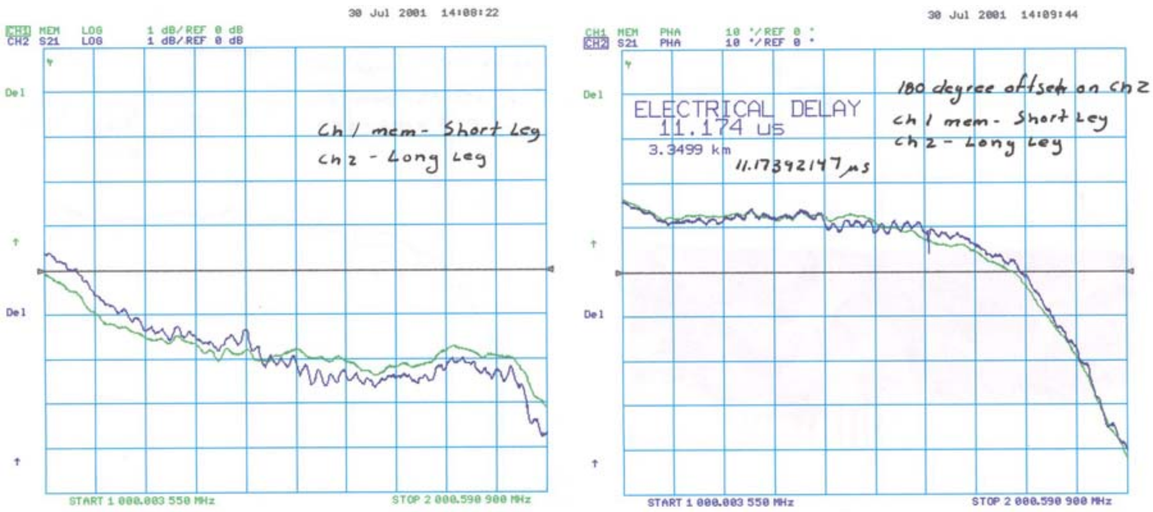

Fig. 4. Magnitude and phase of the 1.0 - 2.0 GHz notch filter

A final test of the notch filter is to measure the notch depth. This is done with the network analyzer in list mode. The network analyzer is programmed to measure frequencies at the top and bottom of the notches. Fig. 5 shows the notch depth measurement of the 0.5-1.0 GHz filter, and fig. 6 shows the notch depth measurement of the 1.0-2.0 GHz notch filter.

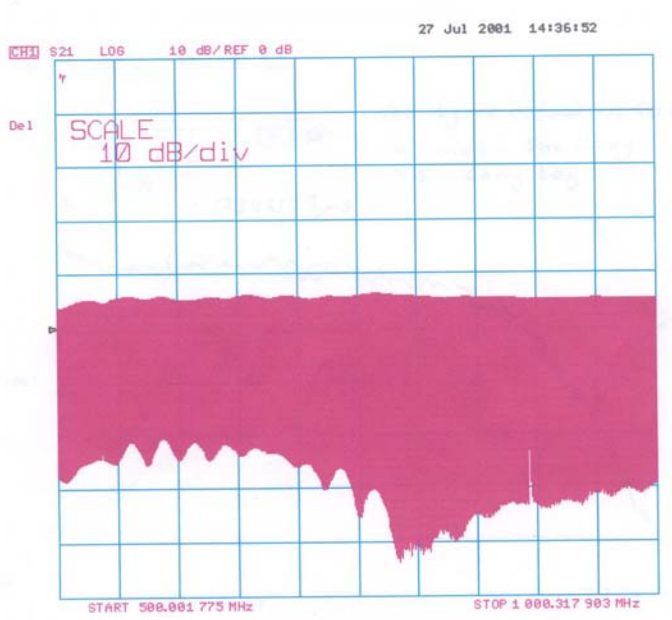

Fig. 5. Notch depth of the 0.5 –1.0 GHz notch filter

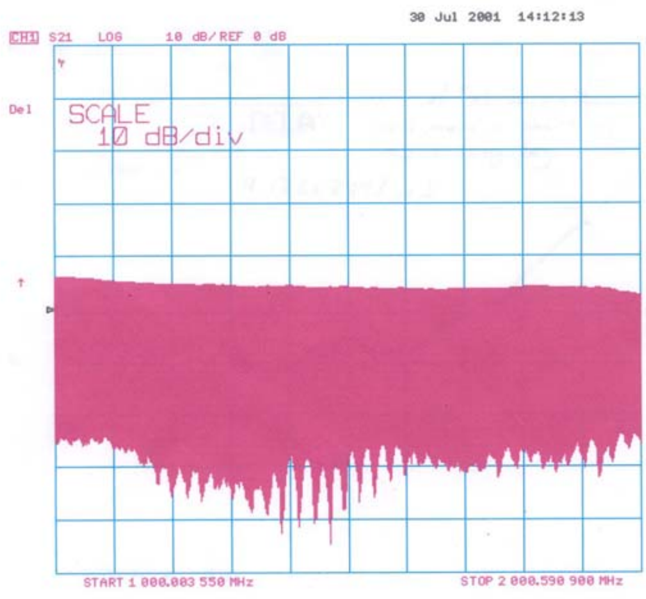

Fig. 6. Notch depth of the 1.0 –2.0 GHz notch filter

When the measurements were made on the notch filters, the revolution frequency of the machine was 89815.3 Hz. The revolution frequency has since changed to 89813.23 Hz. To correct for the difference in frequency, the electrical length of the fiber optical link was changed by changing the temperature from 110 degrees, to 103 degrees F.