Filter Objects

Introduction

A **Filter** object manages a single filter on a controller. It represents the control algorithm used to control a motor in a closed-loop system. The Filter contains an algorithm, a set of coefficients, inputs, and an output. Its primary responsibility is to take the difference between the command and actual positions and then calculate the output based on the control algorithm and coefficients.

For simple systems, there is a one-to-one relationship between the Axis, Filter, and Motor objects.

Methods

Create, Delete, Validate Methods

mpiFilter**Create**	Create Filter object
mpiFilter**Delete**	Delete Filter object
mpiFilter**Validate**	Validate Filter object

Configuration and Information Methods

mpiFilter**ConfigGet**	Get Filter configuration
mpiFilter**ConfigSet**	Set Filter configuration
mpiFilter**FlashConfigGet**	Get flash configuration for Filter
mpiFilter**FlashConfigSet**	Set flash configuration for Filter
mpiFilter**GainGet**	Get gain coefficients
mpiFilter**GainSet**	Set current gain index
mpiFilter**GainIndexGet**	Get current gain index
mpiFilter**GainIndexSet**	Set current gain index

Memory Methods

mpiFilter**Memory**	Get address to Filter memory
mpiFilter**MemoryGet**	Copy data from Filter memory to application memory
mpiFilter**MemorySet**	Copy data from application memory to Filter memory

Relational Methods

mpiFilter**AxisMapGet**	Get object map of axes associated with Filter
mpiFilter**AxisMapSet**	Set axes associated with Filter
mpiFilter**Control**	Return handle of Control that is assoiciated with Filter

mpiFilter**MotorMapGet**	Get object map of Motors associated with Filter
mpiFilter**MotorMapSet**	Set Motors to be associated with Filter
mpiFilter**Number**	Get index of Filter (for Control list)

Action Methods

mpiFilter**IntergratorReset**	Reset the integrators of filter.

Postfilter Methods

meiFilter**PostfilterGet**	Reads postfilter information.
meiFilter**PostfilterSet**	Writes postfilter information.
meiFilter**PostfilterSectionGet**	Reads postfilter section information.
meiFilter**PostfilterSectionSet**	Writes postfilter section information.

Data Types

MPIFilter**Coeff**
MPIFilter**Config** / MEIFilter**Config**
MEIFilter**Form**
MPIFilter**Gain**
MEIFilter**GainIndex**
MEIFilter**GainPID**
MEIFilter**GainPIDCoeff**
MEIFilter**GainPIV**
MEIFilter**GainPIVCoeff**
MEIFilter**GainTypePID**
MEIFilter**GainTypePIV**
MPIFilter**Message**
MEIFilter**Type**
MEI**PostfilterSection**

Constants

MPIFilter**CoeffCOUNT_MAX**
MPIFilter**GainCOUNT_MAX**
MEI**MaxBiQuadSections**

mpiFilterCreate

Declaration

```
MPIFilter mpiFilterCreate(MPIControl  control,
                          long        number)
```

Required Header

stdmpi.h

Description

FilterCreate creates a Filter object associated with a filter (***number***), that is located on a motion controller (***control***).
FilterCreate is the equivalent of a C++ constructor.

Return Values	
handle	to an Filter object
MPIHandleVOID	if the Filter object could not be created

See Also

mpiFilterDelete | mpiFilterValidate

mpiFilterDelete

Declaration

```
long mpiFilterDelete(MPIFilter filter)
```

Required Header

stdmpi.h

Description

FilterDelete deletes a Filter object and invalidates its handle (***filter***). FilterDelete is the equivalent of a C++ destructor.

Return Values	
MPIMessageOK	if *FilterDelete* successfully deletes a Filter object and invalidates its handle

See Also

mpiFilterCreate | mpiFilterValidate

mpiFilterValidate

Declaration

```
long mpiFilterValidate(MPIFilter filter)
```

Required Header stdmpi.h

Description **FilterValidate** validates the Filter object and its handle (***filter***).

Return Values	
MPIMessageOK	if Filter is a handle to a valid object.

See Also mpiFilterCreate | mpiFilterDelete

mpiFilterConfigGet

Declaration

```
long mpiFilterConfigGet(MPIFilter        filter,
                        MPIFilterConfig  *config,
                        void             *external)
```

Required Header

stdmpi.h

Description

FilterConfigGet gets a Filter's (***filter***) configuration and writes it into the structure pointed to by ***config***, and also writes it into the implementation-specific structure pointed to by ***external*** (if ***external*** is not NULL).

The Filter's configuration information in ***external*** is in addition to the Filter's configuration information in ***config***, i.e, the Filter's configuration information in ***config*** and in ***external*** is not the same information. Note that ***config*** or ***external*** can be NULL (but not both NULL).

XMP Only	***external*** either points to a structure of type **MEIFilterConfig{}** or is NULL.

Return Values

MPIMessageOK	if *FilterConfigGet* successfully writes the Filter's configuration to the structure(s)

See Also

mpiFilterConfigSet | MEIFilterConfig

mpiFilterConfigSet

Declaration

```
long mpiFilterConfigSet(MPIFilter          filter,
                        MPIFilterConfig   *config,
                        void              *external)
```

Required Header

stdmpi.h

Description

FilterConfigSet sets a Filter's (***filter***) configuration using data from the structure pointed to by ***config***, and from the implementation-specific structure pointed to by ***external*** (if ***external*** is not NULL).

The Filter's configuration information in ***external*** is in addition to the Filter's configuration information in ***config***, i.e, the Filter's configuration information in ***config*** and in ***external*** is not the same information. Note that ***config*** or ***external*** can be NULL (but not both NULL).

XMP Only	external either points to a structure of type MEIFilterConfig{} or is NULL.

Return Values

MPIMessageOK	if *FilterConfigSet* successfully sets the Filter's configuration using data from the structure(s)

See Also

mpiFilterConfigGet | MEIFilterConfig

mpiFilterFlashConfigGet

Declaration

```
long mpiFilterFlashConfigGet(MPIFilter         filter,
                             void              *flash,
                             MPIFilterConfig   *config,
                             void              *external)
```

Required Header

stdmpi.h

Description

FilterFlashConfigGet gets a Filter's (***filter***) flash configuration and writes it into the structure pointed to by ***config***, and also writes it into the implementation-specific structure pointed to by ***external*** (if ***external*** is not NULL).

The Filter's flash configuration information in ***external*** is in addition to the Filter's flash configuration information in ***config***, i.e., the flash configuration information in ***config*** and in ***external*** is not the same information. Note that ***config*** or ***external*** can be NULL (but not both NULL).

XMP Only	***external*** either points to a structure of type **MEIFilterConfig{}** or is NULL.

Return Values

MPIMessageOK	if *FilterFlashConfigGet* successfully writes the Filter's flash configuration to the structure(s) ***flash*** is either an MEIFlash handle or MPIHandleVOID. If ***flash*** is MPIHandleVOID, an MEIFlash object will be created and deleted internally.

See Also

MEIFlash | mpiFilterFlashConfigSet |MEIFilterConfig

mpiFilterFlashConfigSet

Declaration

```
long mpiFilterFlashConfigSet(MPIFilter        filter,
                             void             *flash,
                             MPIFilterConfig  *config,
                             void             *external)
```

Required Header

stdmpi.h

Description

FilterFlashConfigSet sets a Filter's (***filter***) flash configuration using data from the structure pointed to by ***config***, and also using data from the implementation-specific structure pointed to by ***external*** (if ***external*** is not NULL).

The Filter's flash configuration information in ***external*** is in addition to the Filter's flash configuration information in ***config***, i.e., the flash configuration information in ***config*** and in ***external*** is not the same information. Note that ***config*** or ***external*** can be NULL (but not both NULL).

XMP Only	***external*** either points to a structure of type **MEIFilterConfig{}** or is NULL.

Return Values

MPIMessageOK	if *FilterFlashConfigSet* successfully sets the Filter's flash configuration using data from the structure(s) ***flash*** is either an MEIFlash handle or MPIHandleVOID. If ***flash*** is MPIHandleVOID, an MEIFlash object will be created and deleted internally.

See Also

MEIFlash | mpiFilterFlashConfigGet | MEIFilterConfig

mpiFilterGainGet

Declaration

```
long mpiFilterGainGet(MPIFilter      filter,
                      long           gainIndex,
                      MPIFilterGain  *gain)
```

Required Header stdmpi.h

Description

FilterGainGet gets the gain coefficients of a Filter (***filter***, for the gain index specified by ***gainIndex***) and writes them into the structure pointed to by ***gain***.

Return Values	
MPIMessageOK	if *FilterGainGet* successfully writes the gain coefficients to the structure

See Also mpiFilterGainSet

mpiFilterGainSet

Declaration

```
long mpiFilterGainSet(MPIFilter      filter,
                      long           gainIndex,
                      MPIFilterGain  *gain)
```

Required Header

stdmpi.h

Description

FilterGainSet sets the gain coefficients of a Filter (***filter***, for the gain index specified by ***gainIndex***) using data from the structure pointed to by ***gain***.

Return Values	
MPIMessageOK	if *FilterGainSet* successfully sets the gain coefficients of a Filter using data from the structure

See Also

mpiFilterGainGet

mpiFilterGainIndexGet

Declaration

```
long mpiFilterGainIndexGet(MPIFilter filter,
                           long      *gainIndex)
```

Required Header

stdmpi.h

Description

FilterGainIndexGet gets the current gain index of a Filter (***filter***) and writes it to the location pointed to by ***gainIndex***. Reading the gain index tells you what gain table is being used currently.

If the filter is in state MEIXmpSwitchType MEIXmpSwitchTypeMOTION_ONLY, the gain index is automatically changed by the firmware as described at MEIXmpSwitchType. When the filter is in state MEIXmpSwitchType MEIXmpSwitchTypeNONE, the gain index is controlled by the user.

Gain Scheduling is a feature that switches filter gains for the acceleration, deceleration, constant velocity, and idle states of motion. The post filters are not affected by gain scheduling. Standard algorithms are used with gain scheduling (PID, PIV).

Return Values

MPIMessageOK	if *FilterGainIndexGet* successfully writes the gain index to the location

See Also

MPIFilterConfig | mpiFilterConfigGet | mpiFilterConfigSet | MEIFilterGainIndex | MEIXmpSwitchType | mpiFilterGainIndexSet | mpiFilterGainIndexGet | mpiFilterGainGet | mpiFilterGainSet

mpiFilterGainIndexSet

Declaration

```
long mpiFilterGainIndexSet(MPIFilter   filter,
                           long        gainIndex)
```

Required Header

stdmpi.h

Description

FilterGainIndexSet sets the current gain index of a Filter (***filter***) to ***gainIndex***. Writing the gain index controls what gain table is currently being used.

If the filter is in state MEIXmpSwitchType **MEIXmpSwitchTypeMOTION_ONLY**, the gain index is changed automatically by the firmware as described at MEIXmpSwitchType. Be aware that the filter can change the gain index in real-time, thereby overwriting your changes in this mode.

When the filter is in state MEIXmpSwitchType **MEIXmpSwitchTypeNONE**, the gain index is controlled by the user. This is the normal state when using FilterGainIndexSet(...). Gain Scheduling is a feature that switches filter gains for the acceleration, deceleration, constant velocity, and idle states of motion. The post filters are not affected by gain scheduling. Standard algorithms are used with gain scheduling (PID, PIV).

Return Values

MPIMessageOK	if *FilterGainIndexSet* successfully sets the current gain index to ***gainIndex***

See Also

MPIFilterConfig | mpiFilterConfigGet | mpiFilterConfigSet | MEIFilterGainIndex | MEIXmpSwitchType | mpiFilterGainIndexSet | mpiFilterGainIndexGet | mpiFilterGainGet | mpiFilterGainSet

mpiFilterMemory

Declaration

```
long mpiFilterMemory(MPIFilter  filter,
                     void       **memory)
```

Required Header

stdmpi.h

Description

FilterMemory writes an address, which is used to access a Filter's (***filter***) memory to the contents of ***memory***. This address, or an address calculated from it, can be passed as the src parameter to **MPIFilterMemoryGet(...)** and as the ***dst*** parameter to **MPIFilterMemorySet(...)**.

Return Values	
MPIMessageOK	if *FilterMemory* successfully writes the Filter's memory address to the contents of ***memory***

See Also

mpiFilterMemoryGet | mpiFilterMemorySet

mpiFilterMemoryGet

Declaration

```
long mpiFilterMemoryGet(MPIFilter filter,
                        void      *dst,
                        void      *src,
                        long      count)
```

Required Header

stdmpi.h

Description

FilterMemoryGet copies ***count*** bytes of a Filter's (***filter***) memory (starting at address src) and writes them into application memory (starting at address ***dst***).

Return Values	
MPIMessageOK	if *FilterMemoryGet* successfully copies data from Filter memory to application memory

See Also

mpiFilterMemorySet | mpiFilterMemory

mpiFilterMemorySet

Declaration

```
long mpiFilterMemorySet(MPIFilter filter,
                        void      *dst,
                        void      *src,
                        long      count)
```

Required Header

stdmpi.h

Description

FilterMemorySet copies ***count*** bytes of application memory (starting at address ***src***) and writes them into a Filter's (***filter***) memory (starting at address ***dst***).

Return Values	
MPIMessageOK	if *FilterMemoryGet* successfully copies data from application memory to Filter memory

See Also

mpiFilterMemoryGet | mpiFilterMemory

mpiFilterAxisMapGet

Declaration

```
long mpiFilterAxisMapGet(MPIFilter     filter,
                         MPIObjectMap *axisMap)
```

Required Header

stdmpi.h

Description

FilterAxisMapGet gets the object map of the Axes that are associated with a Filter (***filter***), and writes it into the structure pointed to by ***axisMap***.

Return Values	
MPIMessageOK	if *FilterAxisMapGet* successfully writes the object map of Axes to the structure

See Also

mpiFilterAxisMapSet

mpiFilterAxisMapSet

Declaration

```
long mpiFilterAxisMapSet(MPIFilter     filter,
                         MPIObjectMap axisMap)
```

Required Header

stdmpi.h

Description

FilterAxisMapSet sets the Axes associated with a Filter (***filter***), using data from the object map specified by ***axisMap***.

Return Values

MPIMessageOK	if *FilterAxisMapSet* successfully sets the Axes using the object map

See Also

mpiFilterAxisMapGet

mpiFilterControl

Declaration `MPIControl mpiFilterControl(MPIFilter filter)`

Required Header stdmpi.h

Description **FilterControl** returns a handle to the motion controller (Control object) associated with the specified Filter object (***filter***).

Return Values	
handle	to a Control object that a Filter object is associated with
MPIHandleVOID	if the Filter object is invalid

See Also

mpiFilterMotorMapGet

Declaration

```
long mpiFilterMotorMapGet(MPIFilter     filter,
                          MPIObjectMap  *motorMap)
```

Required Header

stdmpi.h

Description

FilterMotorMapGet gets the object map of the Motors associated with the Filter (***filter***), and writes it into the structure pointed to by ***motorMap***.

Return Values	
MPIMessageOK	if *FilterMotorMapGet* successfully writes the object map of the Motors to the structure

See Also

mpiFilterMotorMapSet

mpiFilterMotorMapSet

Declaration

```
long mpiFilterMotorMapSet(MPIFilter    filter,
                          MPIObjectMap motorMap)
```

Required Header

stdmpi.h

Description

FilterMotorMapSet sets the Motors associated with the Filter (***filter***) using data from the object map specified by ***motorMap***.

Return Values	
MPIMessageOK	if *FilterMotorMapGet* successfully sets the Motors using data from the object map

See Also

mpiFilterMotorMapGet

mpiFilterNumber

Declaration

```
long mpiFilterNumber(MPIFilter  filter,
                     long       *number)
```

Required Header

stdmpi.h

Description

For a motion controller that ***filter*** is associated with, **FilterNumber** writes the index of ***filter*** to the contents of ***number***.

Return Values	
MPIMessageOK	if *FilterNumber* successfully writes the index of a Filter to the contents of **number**

See Also

mpiFilterIntegratorReset

Declaration

```
long mpiFilterIntegratorReset(MPIFilter filter)
```

Required Header stdmpi.h

Description **FilterIntegratorReset** resets the integrators of filter.

Return Values	
MPIMessageOK	if *mpiFilterIntegratorReset* successfully clears the integrators of ***filter***.
MPIFilterMessageINVALID_ALGORITHM	if the ***filter's*** current algorithm does not use integrators.

Sample Code

```
/* Enable the amplifier for every motor attached to a motion supervisor */
void motionAmpEnable(MPIMotion  motion)
{
        MPIControl             control;
        MPIAxis                axis;
        MPIMotor               motor;
        MPIFilter              filter;
        MPIObjectMap    map;
        MPIObjectMap    motionMotorMap;
        long                   motorIndex;
        long                   filterIndex;
        long                   returnValue;
        double                 position;
        long                   enableState;


        /* Get the controller handle */
        control = mpiMotionControl(motion);

        for (axis =  mpiMotionAxisFirst(motion);
                axis != MPIHandleVOID;
                axis =  mpiMotionAxisNext(motion, axis)) {

                /* Get the object map for the motors */
                returnValue = mpiAxisMotorMapGet(axis, &map);
                msgCHECK(returnValue);

                /* Add map to motionMotorMap */
                motionMotorMap |= map;
        }

        /* For every motor ... */
        for (motorIndex = 0; motorIndex < MEIXmpMAX_Motors; motorIndex++) {

                if (mpiObjectMapBitGET(motionMotorMap, motorIndex)) {

                        /* Create motor handle */
                        motor = mpiMotorCreate(control, motorIndex);
```

```
msgCHECK(mpiMotorValidate(motor));

/* Get the state of the amplifier */
returnValue = mpiMotorAmpEnableGet(motor, &enableState);
msgCHECK(returnValue);

/* If the amplifier is disabled ... */
if (enableState == FALSE) {

        /* For every axis */
        for (axis =  mpiMotionAxisFirst(motion);
                 axis != MPIHandleVOID;
                 axis =  mpiMotionAxisNext(motion, axis)) {

                /* Get the object map for the motors */
                returnValue = mpiAxisMotorMapGet(axis, &map);
                msgCHECK(returnValue);

                /* If axis is attached to motor ... */
                if (mpiObjectMapBitGET(map, motorIndex)) {

                        /* Get the actual position of the axis */
                        returnValue = mpiAxisActualPositionGet(axis, &position);
                        msgCHECK(returnValue);

                        /* Set command position equal to actual position */
                        returnValue = mpiAxisCommandPositionSet(axis, position);
                        msgCHECK(returnValue);
                }
        }

        /* Get the object map for the filters */
        returnValue = mpiMotorFilterMapGet(motor, &map);
        msgCHECK(returnValue);

        /* For every filter ... */
        for (filterIndex = 0;
                 filterIndex < MEIXmpMAX_Filters;
                 filterIndex++) {

                if (mpiObjectMapBitGET(map, filterIndex)) {

                        /* Create filter handle */
                        filter = mpiFilterCreate(control, filterIndex);
                        msgCHECK(mpiFilterValidate(filter));

                        /* Reset integrator */
                        returnValue = mpiFilterIntegratorReset(filter);
                        msgCHECK(returnValue);

                        /* Delete filter handle */
                        returnValue = mpiFilterDelete(filter);
                        msgCHECK(returnValue);
                }
        }

        /* Enable the amplifier */
        returnValue = mpiMotorAmpEnableSet(motor, TRUE);
        msgCHECK(returnValue);
}

/* Delete motor handle */
```

```
                returnValue = mpiMotorDelete(motor);
                msgCHECK(returnValue);
            }
        }
    }
```

See Also MPIFilter | MEIFilterConfig | MEIFilterGainPID | MEIFilterGainPIV
mpiAxisActualPositionGet | mpiAxisCommandPositionSet

Troubleshooting / Helpful Hints

If an axis is not in an error state and the filter associated with that axis' motor has a non-zero integration term, then it is very likely that the integrator has built up a substantial integral term. Enabling the motor's amplifier when this has happened could cause the motor to jump with enormous force. Use **mpiFilterIntegratorReset** to reset the integrator before enabling the motor's amplifier to prevent this kind of jump.

Another condition that can cause the motor to jump upon enabling its amplifier is that the command position of the axis is not equal to the actual position of the axis. To prevent this situation, one should use **mpiAxisActualPositionGet** and **mpiAxisCommandPositionSet**. Please refer to this functions for a more in depth discussion.

meiFilterPostfilterGet

Declaration

```
long meiFilterPostfilterGet(MPIFilter               filter,
                            long                    *sectionCount,
                            MEIPostfilterSection    *sections);
```

Required Header

stdmei.h

Description

PostfilterGet reads an MPIFilter object's postfilter configuration. It writes to ***sectionCount*** the number of sections within a postfilter if ***sectionCount*** is not NULL. It also writes to ***sections*** the current array of ***filter***'s postfilter sections if sections is not NULL.

The MPI calculates the post filter coefficients and takes into consideration the sample rate of the controller at that time. If you change the sample rate of the controller, you will need to recalculate the post filters. This can be done for all filters specified in Hertz by setting the filters again with the MPI. The MPI will calculate the filters using the current servo sample rate.

Postfilters are used to digitally filter the output of a control loop. One common use for postfilters is the compensation of system resonances.

filter	the handle of the MPIFilter object whose postfilter configuration is to be read.
***sectionCount**	the data location where the postfilter's current section count will be written.
***sections**	the data location where the postfilter's current section configuration data will be written.

Sample Code

```
/*   Count the number of resonator sections in a MPIFilter object's postfilter.
     Sample usage:

     returnValue =
         filterResonatorCount(filter, &resonatorCount);
*/

long filterResonatorCount(MPIFilter filter, long* count)
{
     MPIFilterConfig config;
     MEIPostfilterSection sections[MEIMaxBiQuadSections];
     long sectionCount, index;
     long returnValue = (count==NULL) ? MPIMessageARG_INVALID : MPIMessageOK;

     if (returnValue == MPIMessageOK)
     {
         returnValue =
             meiFilterPostfilterGet(filter, &sectionCount, sections);

         if (returnValue == MPIMessageOK)
         {
```

```
                for (*count=0, index=0; index sectionCount; ++index)
                {
                    if (section[index].type == MEIFilterTypeRESONATOR) ++(*count);
                }
            }
        }
        return returnValue;
}
```

Return Values

MPIMessageOK	if *PostfilterGet* successfully retrieves postfilter information.
MPIFilterMessageCONVERSION_DIV_BY_0	Returned when meiFilterPostfilterGet(...) cannot convert digital coefficients to analog coefficients. When this error occurs, the offending section(s) will report its type as MEIFilterTypeUNKNOWN and will not contain any analog data.
MPIFilterMessagePOSTFILTER_NOT_ENABLED	Returned when sections is not NULL and when no postfilter sections are enabled.
MPIFilterMessageINVALID_FILTER_FORM	Returned when meiFilterPostfilterGet(...) cannot interpret the current postfilter's form (when the form is something other than NONE, IIR, or BIQUAD).

See Also MEIPostfilterSection | meiFilterPostfilterGet | meiFilterPostfilterSet | meFilterPostfilterSectionGet | MEIMaxBiQuadSections |

Post Filter Theory section.

meiFilterPostfilterSet

Declaration

```
long meiFilterPostfilterSet(MPIFilter              filter,
                            long                   *sectionsCount,
                            MEIPostfilterSection   *sections);
```

Required Header

stdmei.h

Description

PostfilterSet sets the number of postfilter sections within an MPIFilter object and configures each postfilter section as well. If ***numberOfSections*** equals zero, then ***sections*** can be NULL and the postfilter will be disabled.

The MPI calculates the post filter coefficients and takes into consideration the sample rate of the controller at that time. If you change the sample rate of the controller, you will need to recalculate the post filters. This can be done for all filters specified in Hertz by setting the filters again with the MPI. The MPI will calculate the filters using the current servo sample rate.

Postfilters are used to digitally filter the output of a control loop. One common use for postfilters is the compensation of system resonances.

filter	the handle of the MPIFilter object whose postfilter sections will be configured.
***sectionsCount**	the number of postfilter sections to set in the ***filter*** object.
***sections**	a pointer to an array of MEIPostfilterSection data structures to be set in ***filter***.

Sample Code

```
/*   Set a 4th order low-pass post-filter by using two 2nd order low-pass sections.
     Sample usage:

     returnValue =
         fourthOrderLowPass(filter, 300 /* Hz */);
*/
long filterFouthOrderLowpass(MPIFilter filter, long breakPointFrequency)
{
    MPIFilterConfig config;
    MEIPostfilterSection section[MEIMaxBiQuadSections];
    long returnValue;

    section[0].type = MEIFilterTypeLOW_PASS;
    section[0].form = MEIFilterFormINT_BIQUAD;
    section[0].data.lowPass.breakpoint = breakPointFrequency;
    section[1] = section[0]; /* copy first section */

    returnValue =
        meiFilterPostfilterSet(filter, 2, section);

    return returnValue;
}
```

Return Values

MPIMessageOK	if *PostfilterSet* successfully writes postfilter information.

See Also

MEIPostfilterSection | meiFilterPostfilterGet | meFilterPostfilterSectionSet | MEIMaxBiQuadSections |

Post Filter Theory section.

meiFilterPostfilterSectionGet

Declaration

```
long meiFilterPostfilterSectionGet(MPIFilter              filter,
                                   long                   sectionNumber,
                                   MEIPostfilterSection   *section);
```

Required Header

stdmei.h

Description

PostfilterSectionGet reads the configuration of a single section of an MPIFilter object's postfilter. It writes to ***section** the configuration of ***filter***'s postfilter ***sectionNumber***th section.

The MPI calculates the post filter coefficients and takes into consideration the sample rate of the controller at that time. If you change the sample rate of the controller, you will need to recalculate the post filters. This can be done for all filters specified in Hertz by setting the filters again with the MPI. The MPI will calculate the filters using the current servo sample rate.

Postfilters are used to digitally filter the output of a control loop. One common use for postfilters is the compensation of system resonances.

filter	the handle of the MPIFilter object whose postfilter section configuration is to be read.
sectionNumber	the index of the postfilter section whose configuration is to be read.
section	the data location where the postfilter's current section configuration data will be written.

Sample Code

```
/*   Test a section of a MPIFilter object's postfilter to see if it is a notch type.
     Sample usage:

     returnValue =
         isSectionTypeNotch(filter, 0, &isNotch);
*/
long isSectionTypeNotch(MPIFilter filter, long sectionIndex, long* isNotch)
{
    MPIFilterConfig config;
    MEIPostfilterSection section;
    long returnValue = (isNotch==NULL) ? MPIMessageARG_INVALID : MPIMessageOK;

    if (returnValue == MPIMessageOK)
    {
        returnValue =
            meiFilterPostfilterSectionGet(filter, sectionIndex, §ion);
        if (returnValue == MPIMessageOK)
        {
            *isNotch = (section.type == MEIFilterTypeNOTCH) ? TRUE : FALSE;
        }
     }

     return returnValue;
}
```

Return Values

MPIMessageOK	if *PostfilterSectionGet* successfully reads postfilter section information.
MPIFilterMessageCONVERSION_DIV_BY_0	Returned when meiFilterPostfilterSectionGet(...) cannot convert digital coefficients to analog coefficients. When this error occurs, the section will report its type as MEIFilterTypeUNKNOWN and will not contain any analog data.
MPIFilterMessageSECTION_NOT_ENABLED	Returned when no postfilter sections are enabled.
MPIFilterMessageINVALID_FILTER_FORM	Returned when meiFilterPostfilterSectionGet(...) cannot interpret the current postfilter's form (when the form is something other than NONE, IIR, or BIQUAD).

See Also

MEIPostfilterSection | meiFilterPostfilterGet | meFilterPostfilterSectionSet | MEIMaxBiQuadSections |

Post Filter Theory section.

meiFilterPostfilterSectionSet

Declaration

```
long meiFilterPostfilterSectionSet(MPIFilter              filter,
                                   long                   sectionNumber,
                                   MEIPostfilterSection   *section);
```

Required Header

stdmei.h

Description

PostfilterSectionSet sets the configuration of a single section of an MPIFilter object's postfilter. It sets ***filter***'s postfilter ***sectionNumber***th section to the configuration specified in ****section***. If the postfilter type is IIR, then this method is essentially equivalent to meiFilterPostfilterSet().

The MPI calculates the post filter coefficients taking into consideration the sample rate of the controller at that time. If you change the change the sample rate of the controller, you will need to recalculate your post filters. This can be done for all filters specified in Hertz by setting the filters again using the MPI. The MPI will calculate the filters using the current servo sample rate.

Postfilters are used to digitally filter the output of a control loop. One common use for postfilters is the compensation of system resonances.

filter	the handle of the MPIFilter object whose postfilter section configuration is to be set.
sectionNumber	the index of the postfilter section whose configuration is to be set.
***section**	the data location of the section configuration to copy to the controller.

Sample Code

```
/*   Set a section of a MPIFilter object's postfilter to a unity gain filter type.
     Sample usage:

     returnValue =
         setSectionTypeUnityGain(filter, 3);
*/
long setSectionTypeUnityGain(MPIFilter filter, long sectionIndex)
{
    MPIFilterConfig config;
    MEIPostfilterSection section;
    long returnValue;

    section.type = MEIFilterTypeUNITY_GAIN;
    section.form = MEIFilterFormBIQUAD;

    returnValue =
        meiFilterPostfilterSectionSet(filter, sectionIndex, §ion);

    return returnValue;
}
```

Return Values

MPIMessageOK	if *PostfilterSectionSet* successfully writes postfilter section information.

See Also MEIPostfilterSection | meiFilterPostfilterSet | meFilterPostfilterSectionGet | MEIMaxBiQuadSections |

Post Filter Theory section.

MPIFilterCoeff

MPIFilterCoeff

```
typedef union {
    float   f;
    long    l;
} MPIFilterCoeff;
```

Description

f	float coefficient
l	long coefficient

See Also

MPIFilterCoeffCOUNT_MAX | MEIFilterGainPIDCoeff | MEIFilterGainPIVCoeff

MPIFilterConfig / MEIFilterConfig

MPIFilterConfig

```
typedef struct MPIFilterConfig {
    long            gainIndex;
    MPIFilterGain   gain[MPIFilterGainCOUNT_MAX];

    MPIObjectMap    axisMap;
    MPIObjectMap    motorMap;
} MPIFilterConfig;
```

Description

gainIndex	gain table index. Gain tables number 0 to MPIFilterGainCOUNT_MAX -1 (MPIFilterGainCOUNT_MAX = 4).
gain	see MPIFilterGain
axisMap	see MPIObjectMap
motorMap	see MPIObjectMap

MEIFilterConfig

```
typedef struct MEIFilterConfig {
    MEIXmpAlgorithm       Algorithm;

    MEIXmpAxisInput       Axis[MEIXmpFilterAxisInputs];

    long                  *VelPositionPtr;

    MEIXmpSwitchType      GainSwitchType;
    float                 GainDelay;
    long                  GainWindow;
    MEIXmpSwitchType      PPISwitchType;
    MEIXmpPPIMode         PPIMode;
    float                 PPIDelay;
    long                  PPIWindow;
    MEIXmpIntResetConfig  ResetIntegratorConfig;
    float                 ResetIntegratorDelay;

    MEIXmpFilterForm      PostFilterForm;
    MEIXmpPostFilter      PostFilter;
} MEIFilterConfig;
```

Description

MEIFilterConfig contains configuration information specific to a controller. With the exception of the Algorithm element, MEIFilterConfig contains configuration information that are more intuitively accessed by other means (Postfilter parameter) or information for advanced setups and custom controller firmware.

Algorithm	This value defines the algorithm that the filter is executing every servo cycle. The most common values are: MEIXmpAlgorithmPID PID algorithm MEIXmpAlgorithmPIV PIV algorithm MEIXmpAlgorithmNONE No control algorithm
Axis [MEIXmpFilterAxisInputs]	This array defines the axis (pointer to the axis) and coefficient for the position input into the filter. The input to the filter is the position error of the axis, which is multiplied by the coefficient defined by the Axis array.
VelPositionPtr	Velocity position pointer to an encoder input for algorithms that require a velocity encoder position input (such as the PIV algorithm).
AuxInput [MEIXmpFilterAuxInputs]	This array is a place holder for additional filter inputs from analog sources. This is currently not supported and is reserved for future use.
GainSwitchType	Value to define the gain table switch type. Not implemented in standard firmware.
GainDelay	Custom Delay Not implemented in standard firmware.
GainWindow	Custom Delay Not implemented in standard firmware.
PPISwitchType	Value to define the gain switch type for PPI mode. Not implemented in standard firmware.
PPIMode	Value to define the PPI switch mode. Not implemented in standard firmware.
PPIDelay	Custom Delay Not implemented in standard firmware.
PPIWindow	Custom Window Not implemented in standard firmware.
ResetIntegratorConfig	Value to define the integrator's reset configuration. Not supported in standard firmware.
ResetIntegratorDelay	Value to define the integrator's reset delay. Not supported in standard firmware.
PostFilterForm	This value defines the form for postfilters when they are configured using mpiFilterConfigGet/Set(). Supported values are: • **MEIXmpFilterFormIIR**, IIR Filter • **MEIXmpFilterFormBIQ**, Bi-Quad Filter • **MEIXmpFilterFormSS_BIQ**, State Space form of Bi-Quad Filter

	• **MEIXmpFilterFormINT_BIQ**, Integer (64-bit) Bi-Quad Filter • **MEIXmpFilterFormINT_SS_BIQ**, Integer State Space form of Bi-Quad Filter Though the postfilter may be configured through this parameter, it is strongly recommended that users use the meiFilterPostfilter…() methods instead for a more intuitive and user-friendly interface.
PostFilter	This array defines the configuration for the filter's postfilter (the type, the length and values for the post filter coefficients). Though the postfilter may be configured though this parameter, it is strongly recommended that users use the meiFilterPostfilter…() methods instead for a more intuitive interface. Postfilters are used to digitally filter the output of a control loop. One common use for postfilters is the compensation of system resonances.

Sample Code

```
/*   Test whether an MPIFilter object's control loop algorithm is PID.
     Sample usage:

     returnValue =
         isAlgorithmPid(filter, &isPid);
*/

long isAlgorithmPid(MPIFilter filter, long* isPid)
{
     MEIFilterConfig xmpConfig;
     long returnValue = (isPid==NULL) ? MPIMessageARG_INVALID : MPIMessageOK;

     if (returnValue == MPIMessageOK)
     {
         returnValue =
             mpiFilterConfigGet(filter, NULL, &xmpConfig);
         if (returnValue == MPIMessageOK)
         {
             *isPid = (xmpConfig.Algorithm == MEIXmpAlgorithmPID) ? TRUE : FALSE;
         }
      }

      return returnValue;
}
```

See Also mpiFilterConfigGet | mpiFilterConfigSet | meiFilterPostfilterGet | meiFilterPostfilterSet | meiFilterPostfilterSectionGet | meiFilterPostfilterSectionSet |

MEIFilterForm

MEIFilterForm

```
typedef enum{
    MEIFilterFormIIR,
    MEIFilterFormBIQUAD,
    MEIFilterFormSS_BIQUAD,
    MEIFilterFormINT_BIQUAD,
    MEIFilterFormINT_SS_BIQUAD,
} MEIFilterForm;
```

Description

FilterForm describes the form that a digital filter takes on the controller. Please note that the equations listed below use the coefficients loaded onto the controller, not necessarily the coefficients used by the MPI. A user may specify a low pass filter with only a single parameter (the breakpoint) and request that the form of the filter be a space-state biquad form on the controller.

Digital filtering on the XMP is accomplished through 32-bit words. This equates to the use of single precision floating point numbers - a 24-bit mantissa or about 7 decimal places of accuracy. This lack of precision can cause errors in the filtering process normally appearing as DC gain shifts or limit cycling, this especially true when the filter requires more than one section, a 6th order low pass filter would be one example. Filter forms using integer math can provide more internal precision for coefficients and internal registers but at the cost of less dynamic range. Filter forms using integer math take more processing time for the controller and can potentially limit the maximum sample rate of the controller.

The state-space (SS) filter forms allow the scaling of the input and the output, whereas the non-state-space forms only allow output scaling. This helps to prevent the loss of precision of the internal registers while still maintaining a very large dynamic range. Filter forms using state-space forms take more processing time for the controller and can potentially limit the maximum sample rate of the controller. However, a non-integer state-space filter form takes less processing power than an integer non-state-space filter form.

MEIFilterFormIIR	***Deprecated***. Cascaded biquad sections offer better precision and better calculation performance.

MEIFilterFormBIQUAD	Second Order digital filter form, for implementing low/high pass, notch, lead/lag and custom filters. The filter is a single precision floating point canonical form. The biquad filter is defined by the following discrete transfer function: The XMP's representation of this filter is: w0: Intermediate result u(k): filter input a1, a2, b0, b1, and b2: discrete biquad coefficients y(k):filter output x1k and x2k: filter states
MEIFilterFormSS_BIQUAD	Second order digital filter form, for implementing low/high pass, notch, lead/lag and custom filters. The filter is a single precision, floating point state space implementation. This filter applies input and output scaling to the canonical form. The XMP's state space representation of this filter is: u(k): filter input d1, c1, c2, a2, a1,b1: discrete biquad coefficients y(k):filter output p1k and p2k: filter states
MEIFilterFormINT_BIQUAD	Second Order digital filter form, for implementing low/high pass, notch, lead/lag and custom filters. The filter is a fixed point canonical form state space implementation. This form is a fixed point implementation of the floating point form MEIFilterFormBIQUAD. See the definition of MEIFilterFormBIQUAD above for the defining equations for this filter. The input coefficients for this filter (b0, b1, b2, a1 and a2) should all be greater than -2, and less than 2. The coefficients are represented as 32 bit 2's complement, with 1=2^30. The coefficient's numerical format is 1.29 (1 bit whole, 29 bits fractional), and the controller uses an 80 bit accumulator. Only the 32 bit result of the multiplication is output from each section.

MEIFilterFormINT_SS_BIQUAD	Second Order digital filter form, for implementing low/high pass, notch, lead/lag and custom filters. The filter is a fixed point canonical form state space implementation. This form is a fixed point implementation of the floating point form MEIFilterFormSS_BIQUAD. See the definition of MEIFilterFormSS_BIQUAD above for the defining equations for this filter. The input coefficients for this filter (d1, c1, c2, a2, a1 and b1) should all be greater than -2, and less than 2. The coefficients are represented as 32 bit 2's complement, with 1=2^30. The coefficient's numerical format is 1.29 (1 bit whole, 29 bits fractional), and the controller uses an 80 bit accumulator. Only the 32 bit result of the multiplication is output from each section.

See Also

MEIPostfilterSection

MPIFilterGain

MPIFilterGain

```
typedef struct MPIFilterGain {
    MPIFilterCoeff      coeff[MPIFilterCoeffCOUNT_MAX];
} MPIFilterGain;
```

Description

coeff	see MPIFilterCoeff

See Also MPIFilterGainCOUNT_MAX | MEIFilterGainPIDCoeff | MEIFilterGainPIVCoeff

MEIFilterGainIndex

MEIFilterGainIndex

```
typedef enum {

    /* Gain table index for normal firmware. */
    MEIFilterGainIndexNO_MOTION = MEIXmpGainNOT_MOVING,
    MEIFilterGainIndexACCEL     = MEIXmpGainACCEL,
    MEIFilterGainIndexDECEL     = MEIXmpGainDECEL,
    MEIFilterGainIndexVELOCITY  = MEIXmpGainCONSTANT_VEL,

    /* Gain table index for Custom 1 firmware. */
    MEIFilterGainIndexSTOPPING2 = MEIXmpGainSTOPPED2,
    MEIFilterGainIndexSTOPPING1 = MEIXmpGainSTOPPED1,
    MEIFilterGainIndexSETTLING  = MEIXmpGainSETTLING,
    MEIFilterGainIndexMOVING    = MEIXmpGainMOVING,
    MEIFilterGainIndexSTOPPING3 = MEIXmpGainSTOPPED3,

    /* Gain table index for Custom 5 firmware. */
    MEIFilterGainIndexMIN       = MEIXmpGainMIN,
    MEIFilterGainIndexMAX       = MEIXmpGainMAX,
    MEIFilterGainIndexNONE      = MEIXmpGainNONE,
    MEIFilterGainIndexSLOPE     = MEIXmpGainSLOPE,

    MEIFilterGainIndexLAST      = MEIXmpGainLAST,
    MEIFilterGainIndexALL       = MEIFilterGainIndexLAST,
                                        /* used for gain get/set() */
    MEIFilterGainIndexFIRST     = MEIFilterGainIndexINVALID + 1,

    MEIFilterGainIndexDEFAULT   = MEIFilterGainIndexNO_MOTION,
} MEIFilterGainIndex;
```

Description

FilterGainIndex is an enumeration for the gain index used in gain scheduling.

In standard firmware, only
MEIFilterGainIndexNO_MOTION,
MEIFilterGainIndexACCEL,
MEIFilterGainIndexDECEL, and
MEIFilterGainIndexVELOCITY
are used. The gain index that is currently used can be found with mpiFilterGainIndexGet(...).

Gain Scheduling is a feature that switches filter gains for the acceleration, deceleration, constant velocity, and idle states of motion. The post filters are not affected by gain scheduling. Standard algorithms are used with gain scheduling (PID, PIV). To change the gain scheduling type from NONE (uses only the gains in gain table index 0), use MEIFilterConfig. GainSwitchType is set with mpiFilterConfigSet(...).

When setting filter gain parameters using mpiFilterGainGet(...) and mpiFilterGainSet(...), use the gain index value to write to a gain index of your choosing.

MEIFilterGainIndexNO_MOTION	No commanded motion. Trajectory parameters Velocity, Acceleration, and Jerk equal zero.
MEIFilterGainIndexACCEL	Acceleration portion of the commanded move.
MEIFilterGainIndexDECEL	Deceleration portion of the commanded move.
MEIFilterGainIndexVELOCITY	Constant velocity portion of the commanded move. Gain switching is configured by setting the GainSwtichType, GainDelay, and GainWindow in the MEIFilterConfig{...} structure and calling mpiFilterConfigGet/Set(...). The GainSwitchType has the following options:

See Also

MEIFilterConfig | mpiFilterConfigGet | mpiFilterConfigSet | MEIXmpSwitchType | mpiFilterGainIndexSet | mpiFilterGainIndexGet | mpiFilterGainGet | mpiFilterGainSet

MEIFilterGainPID

MEIFilterGainPID

```
typedef struct MEIFilterGainPID {
    struct {
    float   proportional;     /* Kp */
    float   integral;         /* Ki */
    float   derivative;       /* Kd */
    } gain;
    struct {
        float   position;     /* Kpff */
        float   velocity;     /* Kvff */
        float   acceleration; /* Kaff */
        float   friction;     /* Kfff */
    } feedForward;
    struct {
        float   moving;       /* MovingIMax */
        float   rest;         /* RestIMax */
    } integrationMax;
    long    dRate;            /* DRate */
    struct {
        float   limit;        /* OutputLimit */
        float   limitHigh;    /* OutputLimitHigh */
        float   limitLow;     /* OutputLimitLow */
        float   offset;       /* OutputOffset */
    } output;
    struct {
        float   positionFFT;  /* Ka0 */
        float   filterFFT;    /* Ka1 */
        float   velocityFFT;  /* Ka2 */
    } noise;
} MEIFilterGainPID;
```

Description

FilterGainPID is a structure that defines the filter coefficients for the PID filter algorithm.

See Also

High/Low Output Limits section for special instructions regarding MEIFilterGainPID.
MEIFilterGainPIDCoeff

MEIFilterGainPIDCoeff

MEIFilterGainPIDCoeff

```
typedef         enum {
    MEIFilterGainPIDCoeffINVALID = -1,

    MEIFilterGainPIDCoeffGAIN_PROPORTIONAL, /* Kp */
    MEIFilterGainPIDCoeffGAIN_INTEGRAL,     /* Ki */
    MEIFilterGainPIDCoeffGAIN_DERIVATIVE,   /* Kd */


    MEIFilterGainPIDCoeffFEEDFORWARD_POSITION,     /* Kpff */
    MEIFilterGainPIDCoeffFEEDFORWARD_VELOCITY,     /* Kvff */
    MEIFilterGainPIDCoeffFEEDFORWARD_ACCELERATION, /* Kaff */
    MEIFilterGainPIDCoeffFEEDFORWARD_FRICTION,     /* Kfff */


    MEIFilterGainPIDCoeffINTEGRATIONMAX_MOVING, /* MovingIMax */
    MEIFilterGainPIDCoeffINTEGRATIONMAX_REST,   /* RestIMax */


    MEIFilterGainPIDCoeffDRATE,             /* DRate */


    MEIFilterGainPIDCoeffOUTPUT_LIMIT,      /* OutputLimit */
    MEIFilterGainPIDCoeffOUTPUT_LIMITHIGH,  /* OutputLimitHigh */
    MEIFilterGainPIDCoeffOUTPUT_LIMITLOW,   /* OutputLimitLow */
    MEIFilterGainPIDCoeffOUTPUT_OFFSET,     /* OutputOffset */


    MEIFilterGainPIDCoeffNOISE_POSITIONFFT, /* Ka0 */
    MEIFilterGainPIDCoeffNOISE_FILTERFFT,   /* Ka1 */
    MEIFilterGainPIDCoeffNOISE_VELOCITYFFT, /* Ka2 */

} MEIFilterGainPIDCoeff;
```

Description

FilterGainPIDCoeff is a structure of enums that defines the filter coefficients for the PID filter algorithm.

See Also

MEIFilterGainPID

MEIFilterGainPIV

MEIFilterGainPIV

```
typedef         struct MEIFilterGainPIV {
    struct {
        float   proportional;   /* Kpp */
        float   integral;       /* Kip */
    } gainPosition;
    struct {
        float   proportional;   /* Kpv */
    } gainVelocity1;
    struct {
        float   position;       /* Kpff */
        float   velocity;       /* Kvff */
        float   acceleration;   /* Kaff */
        float   friction;       /* Kfff */
    } feedForward;
    struct {
        float   moving;     /* MovingIMax */
        float   rest;       /* RestIMax */
    } integrationMax;
    struct {
        float   feedback;   /* Kdv */
    } gainVelocity2;
    struct {
        float   limit;      /* OutputLimit */
        float   limitHigh;  /* OutputLimitHigh */
        float   limitLow;   /* OutputLimitLow */
        float   offset;     /* OutputOffset */
    } output;
    struct {
        float   integral;        /* Kiv */
        float   integrationMax;  /* VintMax */
    } gainVelocity3;
    struct {
        float   positionFFT;  /* Ka0 */
        float   filterFFT;    /* Ka1 */
    } noise;
} MEIFilterGainPIV;
```

Description

FilterGainPIV is a structure that defines the filter coefficients for the PIV filter algorithm.

See Also

High/Low Output Limits section for special instructions regarding MEIFilterGainPIV.
MEIFilterGainPIVCoeff

MEIFilterGainPIVCoeff

MEIFilterGainPIVCoeff

```
typedef         enum {
    MEIFilterGainPIVCoeffINVALID = -1,

    MEIFilterGainPIVCoeffGAINPOSITION_PROPORTIONAL,     /* Kpp */
    MEIFilterGainPIVCoeffGAINPOSITION_INTEGRAL,         /* Kip */


    MEIFilterGainPIVCoeffGAINVELOCITY_PROPORTIONAL,     /* Kpv */


    MEIFilterGainPIVCoeffFEEDFORWARD_POSITION,          /* Kpff */
    MEIFilterGainPIVCoeffFEEDFORWARD_VELOCITY,          /* Kvff */
    MEIFilterGainPIVCoeffFEEDFORWARD_ACCELERATION,      /* Kaff */
    MEIFilterGainPIVCoeffFEEDFORWARD_FRICTION,          /* Kfff */


    MEIFilterGainPIVCoeffINTEGRATIONMAX_MOVING,         /* MovingIMax */
    MEIFilterGainPIVCoeffINTEGRATIONMAX_REST,           /* RestIMax */


    MEIFilterGainPIVCoeffGAINVELOCITY_FEEDBACK,         /* Kdv */


    MEIFilterGainPIVCoeffOUTPUT_LIMIT,          /* OutputLimit */
    MEIFilterGainPIVCoeffOUTPUT_LIMITHIGH,      /* OutputLimitHigh */
    MEIFilterGainPIVCoeffOUTPUT_LIMITLOW,       /* OutputLimitLow */
    MEIFilterGainPIVCoeffOUTPUT_OFFSET,         /* OutputOffset */


    MEIFilterGainPIVCoeffGAINVELOCITY_INTEGRAL,         /* Kiv */
    MEIFilterGainPIVCoeffGAINVELOCITY_INTEGRATIONMAX,   /* Vintmax */


    MEIFilterGainPIVCoeffNOISE_POSITIONFFT,             /* Ka0 */
    MEIFilterGainPIVCoeffNOISE_FILTERFFT,               /* Ka1 */

} MEIFilterGainPIVCoeff;
```

Description

FilterGainPIVCoeff is a structure of enums that defines the filter coefficients for the PIV filter algorithm.

See Also

High/Low Output Limits section for special instructions regarding MEIFilterGainPIV.
MEIFilterGainPIV

MEIFilterGainTypePID

MEIFilterGainTypePID

```
static MEIDataType MEIFilterGainTypePID[MPIFilterCoeffCOUNT_MAX] =
{
    MEIDataTypeFLOAT, /* Kp              */
    MEIDataTypeFLOAT, /* Ki              */
    MEIDataTypeFLOAT, /* Kd              */

    MEIDataTypeFLOAT, /* Kpff            */
    MEIDataTypeFLOAT, /* Kvff            */
    MEIDataTypeFLOAT, /* Kaff            */
    MEIDataTypeFLOAT, /* Kfff            */

    MEIDataTypeFLOAT, /* MovingIMax      */
    MEIDataTypeFLOAT, /* RestIMax        */

    MEIDataTypeLONG,  /* DRate           */

    MEIDataTypeFLOAT, /* OutputLimit     */
    MEIDataTypeFLOAT, /* OutputLimitHigh */
    MEIDataTypeFLOAT, /* OutputLimitLow  */
    MEIDataTypeFLOAT, /* OutputOffset    */
    MEIDataTypeFLOAT, /* Ka0             */
    MEIDataTypeFLOAT, /* Ka1             */
    MEIDataTypeFLOAT, /* Ka2             */
};
```

Description

FilterGainTypePID is a static array that describes the data type of the coefficients for the PID algorithm. Specifically, an element of MEIFilterGainTypePID describes which member of the union MPIFilterCoeff to access when using the data structure MPIFilterCoeff.

MEIFilterGainTypePID allows for a more simple design of general case utilities and configuration routines. If it is known that only the PID parameters will be used, then the data structure MEIFilterGainPID can be used directly without having to manipulate MPIFilterCoeff, MPIFilterCoeff, and MEIFilterGainTypePID.

Sample Code

```
/*  Read the current value of a filter's PID coefficient.  Sample usage:

    returnValue =
        getPidFilterCoeff(filter, MEIFilterGainPIDCoeffGAIN_PROPORTIONAL, &kp);
*/
long getPidFilterCoeff(MPIFilter filter, long index, double* value)
{

    MPIFilterConfig config;
    long returnValue = (value==NULL) ? MPIMessageARG_INVALID : MPIMessageOK;

    if (returnValue == MPIMessageOK)
    {
        returnValue = mpiFilterConfigGet(filter, &config, NULL);

        if (returnValue == MPIMessageOK)
        {
            switch(MEIFilterGainTypePID[index])
            {
                case MEIDataTypeLONG:
                    *value = config.gain[config.gainIndex].coeff[index].l;
                    break;
                case MEIDataTypeFLOAT:
                    *value = config.gain[config.gainIndex].coeff[index].f;
                    break;
                default:
                    returnValue = MPIMessageARG_INVALID;
             }
         }
    }
return returnValue;
}
```

See Also MPIFilterCoeff | MEIFilterGainTypePIV | MEIFilterGainPID | MEIDataType | MPIFilterGain |

MEIFilterGainTypePIV

MEIFilterGainTypePIV

```
static MEIDataType MEIFilterGainTypePIV[MPIFilterCoeffCOUNT_MAX] =
{
    MEIDataTypeFLOAT, /* Kpp              */
    MEIDataTypeFLOAT, /* Kip              */


    MEIDataTypeFLOAT, /* Kpv              */


    MEIDataTypeFLOAT, /* Kpff             */
    MEIDataTypeFLOAT, /* Kvff             */
    MEIDataTypeFLOAT, /* Kaff             */
    MEIDataTypeFLOAT, /* Kfff             */


    MEIDataTypeFLOAT, /* MovingIMax       */
    MEIDataTypeFLOAT, /* RestIMax         */


    MEIDataTypeFLOAT, /* Kdv              */


    MEIDataTypeFLOAT, /* OutputLimit      */
    MEIDataTypeFLOAT, /* OutputLimitHigh  */
    MEIDataTypeFLOAT, /* OutputLimitLow   */
    MEIDataTypeFLOAT, /* OutputOffset     */


    MEIDataTypeFLOAT, /* Kiv              */
    MEIDataTypeFLOAT, /* Vintmax          */
    MEIDataTypeFLOAT, /* Ka0              */
    MEIDataTypeFLOAT, /* Ka1              */
};
```

Description

FilterGainTypePIV is a static array that describes the data type of the coefficients for the PIV algorithm. Specifically, an element of MEIFilterGainTypePIV describes which member of the union MPIFilterCoeff to access when using the data structure MPIFilterCoeff.

MEIFilterGainTypePIV allows for a more simple design of general case utilities and configuration routines. If it is known that only the PIV parameters will be used, then the data structure MEIFilterGainPIV can be used directly without having to manipulate MPIFilterCoeff, MPIFilterCoeff, and MEIFilterGainTypePIV.

Sample Code

```
/*   Read the current value of a filter's PIV coefficient.  Sample usage:

     returnValue =
         getPivFilterCoeff(filter, MEIFilterGainPIVCoeffGAINVELOCITY_PROPORTIONAL,
&kpv);
*/
long getPivFilterCoeff(MPIFilter filter, long index, double* value)
{
     MPIFilterConfig config;
     long returnValue = (value==NULL) ? MPIMessageARG_INVALID : MPIMessageOK;

     if (returnValue == MPIMessageOK)
     {

         returnValue = mpiFilterConfigGet(filter, &config, NULL);

         if (returnValue == MPIMessageOK)
         {
              switch(MEIFilterGainTypePIV[index])
              {
                   case MEIDataTypeLONG:
                        *value = config.gain[config.gainIndex].coeff[index].l;
                        break;
                   case MEIDataTypeFLOAT:
                        *value = config.gain[config.gainIndex].coeff[index].f;
                        break;
                   default:
                        returnValue = MPIMessageARG_INVALID;
              }
         }
    }

    return returnValue;
}
```

See Also

MPIFilterCoeff | MEIFilterGainTypePID | MEIFilterGainPIV | MEIDataType | MPIFilterGain |

MPIFilterMessage

MPIFilterMessage

```
typedef enum {
    MPIFilterMessageFILTER_INVALID,
    MPIFilterMessageINVALID_ALGORITHM,
    MPIFilterMessageINVALID_DRATE,
        MPIFilterMessageCONVERSION_DIV_BY_0,
        MPIFilterMessagePOSTFILTER_NOT_ENABLED,
        MPIFilterMessageINVALID_FILTER_FORM,
} MPIFilterMessage;
```

Description

MPIFilterMessageFILTER_INVALID

The filter number is out of range. This message code is returned by mpiFilterCreate(…) if the filter number is less than zero or greater than or equal to MEIXmpMAX_Filters.

MPIFilterMessageINVALID_ALGORITHM

The filter algorithm is not valid. This message code is returned by mpiFilterIntegratorReset(…) if the filter algorithm is not a member of the MEIXmpAlgorithm enumeration (does not support integrators). This problem occurs if the filter type is set to user or an unknown type with mpiFilterConfigSet(…).

MPIFilterMessageINVALID_DRATE

The filter derivative rate is not valid. This message code is returned by mpiFilterConfigSet(…) if the filter derivative rate is less than 0 or greater than 7.

NOTE: The derivative rate for all gain tables must be in the range [0,7], not just the derivative rate for the current gain table.

MPIFilterMessageCONVERSION_DIV_BY_0

Returned when meiFilterPostfilterGet(...) or meiFilterPostfilterSectionGet(...) cannot convert digital coefficients to analog coefficients. When this error occurs, the offending section(s) will report its type as MEIFilterTypeUNKNOWN and will not contain any analog data.

MPIFilterMessagePOSTFILTER_NOT_ENABLED

Returned when meiFilterPostfilterGet(...) or meiFilterPostfilterSectionGet(...) attempt to read postfilter data when no postfilter sections are enabled.

MPIFilterMessageINVALID_FILTER_FORM

Returned when meiFilterPostfilterGet(...) or meiFilterPostfilterSectionGet(...) cannot interpret the current postfilter's form (when the form is something other than NONE, IIR, or BIQUAD).

See Also

mpiFilterCreate

MEIFilterType

MEIFilterType

```
typedef enum {
    MEIFilterTypeUNITY_GAIN,
        /* B0 = 1    B1=B2=A1=A2 = 0  (effectively acting as no filter) */
    MEIFilterTypeSINGLE_ORDER,
    MEIFilterTypeLOW_PASS,
    MEIFilterTypeHIGH_PASS,
    MEIFilterTypeNOTCH,
    MEIFilterTypeRESONATOR,
    MEIFilterTypeLEAD_LAG,
    MEIFilterTypeZERO_GAIN,
        /* b0=b1=b2=a1=a2 = 0  (this does act as a filter.... zeroing the output) */
    MEIFilterTypeBIQUAD,
        /* Only valid for setting.  Reading will not return these types */
    MEIFilterTypeDIGITAL_BIQUAD,
    MEIFilterTypePOLES_ZEROS,
    MEIFilterTypeDIGITAL_POLES_ZEROS,
    MEIFilterTypeUNKNOWN,
        /* algorithm couldn't figure out what this filter was from the coeffs! */
} MEIFilterType;
```

Description

NOTE: The MPI will attempt to return analog & digital biquad and pole/zero information from meiFilterPostfilterGet(...) and meiFilterPostfilterSectionGet(...). However, the filter types MEIFilterTypeDIGITAL_BIQUAD, MEIFilterTypePOLES_ZEROS, and MEIFilterTypeDIGITAL_POLES_ZEROS are never returned by get() calls -- they are used only for setting postfilters. MEIFilterTypeBIQUAD will only be returned by meiFilterPostfilterGet(...) and meiFilterPostfilterSectionGet(...) if the analog coefficients can be calculated (there is no division by 0) and the section cannot be identified as one of the other analog filter types.

MEIFilterTypeUNITY_GAIN	A unity gain filter. This effectively performs no filtering.
MEIFilterTypeSINGLE_ORDER	A single order filter
MEIFilterTypeLOW_PASS	A low pass filter
MEIFilterType_HIGH_PASS	A high pass filter.
MEIFilterTypeNOTCH	A notch filter
MEIFilterTypeRESONATOR	A resonator filter.
MEIFilterTypeLEAD_LAG	A lead or lag filter.
MEIFilterTypeZERO_GAIN	Zeros the output of a filter.
MEIFilterTypeBIQUAD	An analog biquad filter. When reading postfilter data, this type means that the postfilter section could not be identified as a standard filter type.
MEIFilterTypeDIGITAL_BIQUAD	A digital biquad filter. This is only used for setting postfilter sections.

MEIFilterTypePOLES_ZERO	Analog poles and zeros filter (maximum of two poles and zeros) with unity zero-frequency amplitude. This is only used for setting postfilter sections.
MEIFilterTypeDIGITAL_POLES_ZEROS	Digital poles and zeros filter (maximum of two poles and zeros) with unity zero-frequency amplitude. This is only used for setting postfilter sections.
MEIFilterTypeUNKNOWN	Returned by meiFilterPostfilterGet(...) and meiFilterPostfilterSectionGet(...) if analog coefficients cannot be found. only digital data will be available.

See Also

MEIPostfilterSection | meiFilterPosterfilterGet | meiFilterPosterfilterSet | meiFilterPosterfilterSectionGet | meiFilterPosterfilterSectionSet

MEIPostfilterSection

MEIPostfilterSection

```
typedef struct MEIPostfilterSection {
   MEIFilterType    type;
   MEIFilterForm    form;
   struct {
        struct {
            double breakPoint;      /* Hz */
        } lowPass;

        struct {
            double breakPoint;     /* Hz */
        } highPass;

        struct {
            double centerFrequency; /* Hz */
            double bandwidth;       /* Hz */
        } notch;

        struct {
            double centerFrequency; /* Hz */
            double bandwidth;       /* Hz */
            double gain;            /* dB */
        } resonator;

        struct {
            double lowFrequencyGain;    /* dB */
            double highFrequencyGain;   /* dB */
            double centerFrequency;     /* Hz */
        } leadLag;

        struct {
            double a1;
            double a2;
            double b0;
            double b1;
            double b2;
        } biquad;

        struct {
            double a1;
            double a2;
            double b0;
            double b1;
            double b2;
        } digitalBiquad;

        struct {
            long poleCount;
            long zeroCount;
            struct {
                double  real;
                double  imag;
            } pole[2];
```

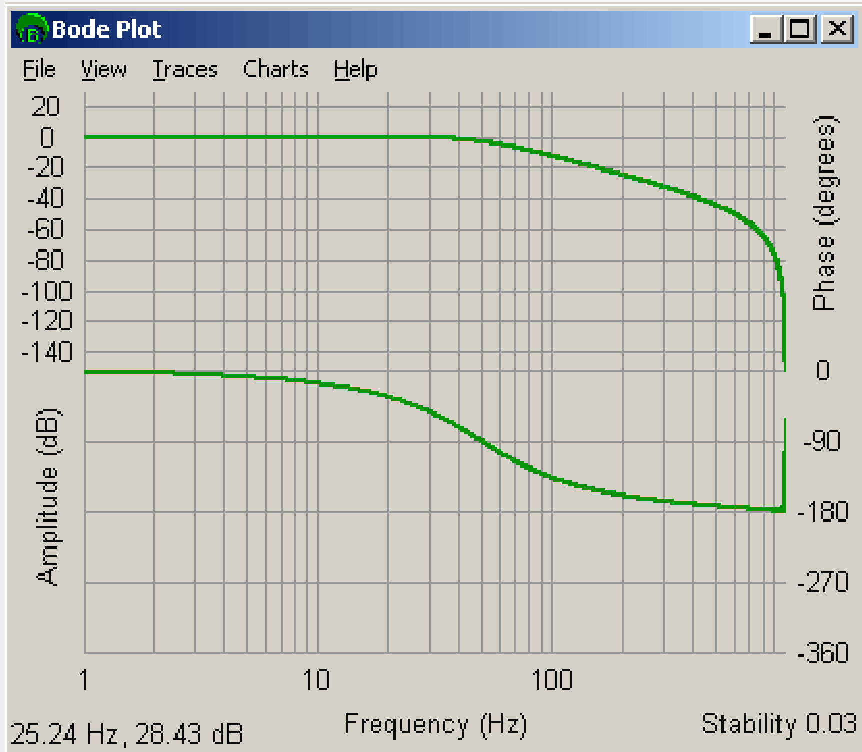
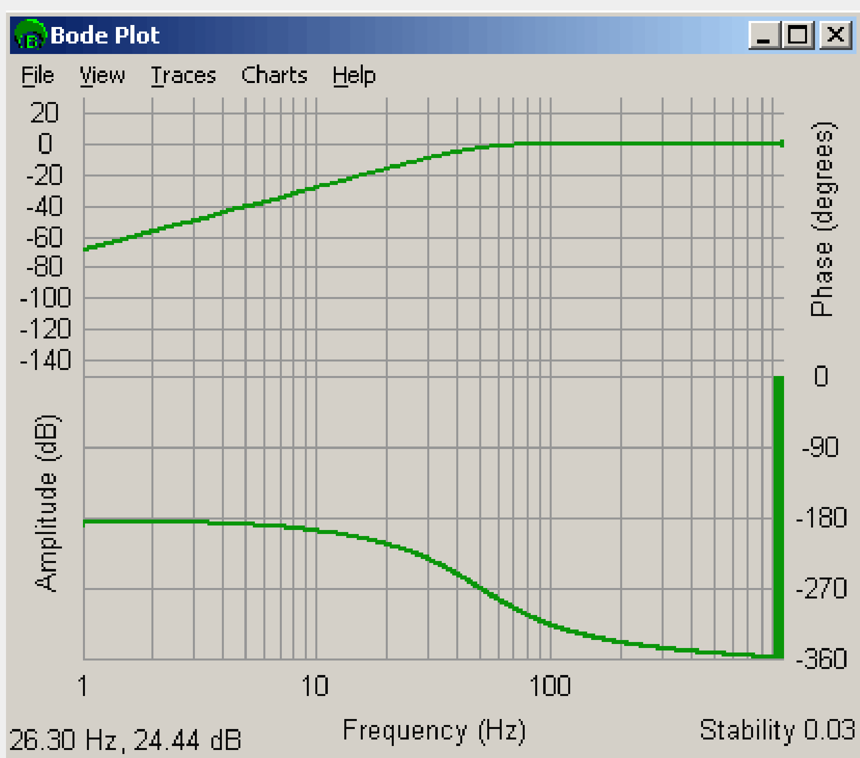
```
                struct {
                    double  real;
                    double  imag;
                } zero[2];
            } polesZeros;

            struct {
                long poleCount;
                long zeroCount;
                struct {
                   double real;
                   double imag;
                } pole[2];
                struct {
                   double real;
                   double imag;
                } zero[2];
            } digitalPolesZeros;

            struct {
                double d1;
                double c1;
                double c2;
                double a2;
                double a1;
                double b1;
            } stateSpaceBiquad;

            struct {
                long    numberOfCoefficients;
                double  coeff[MEIXmpMAX_PostFilterSize];
            } iir;
        } data;
    } MEIPostfilterSection;
```

Description

MEIPostfilterSection holds the configuration data for a single section of an MPIFilter object's postfilter. The MPI calculates the post filter coefficients and takes into consideration the sample rate of the controller at that time. If you change the sample rate of the controller, you will need to recalculate the post filters. This can be done for all filters specified in Hertz by setting the filters again with the MPI. The MPI will calculate the filters using the current servo sample rate.

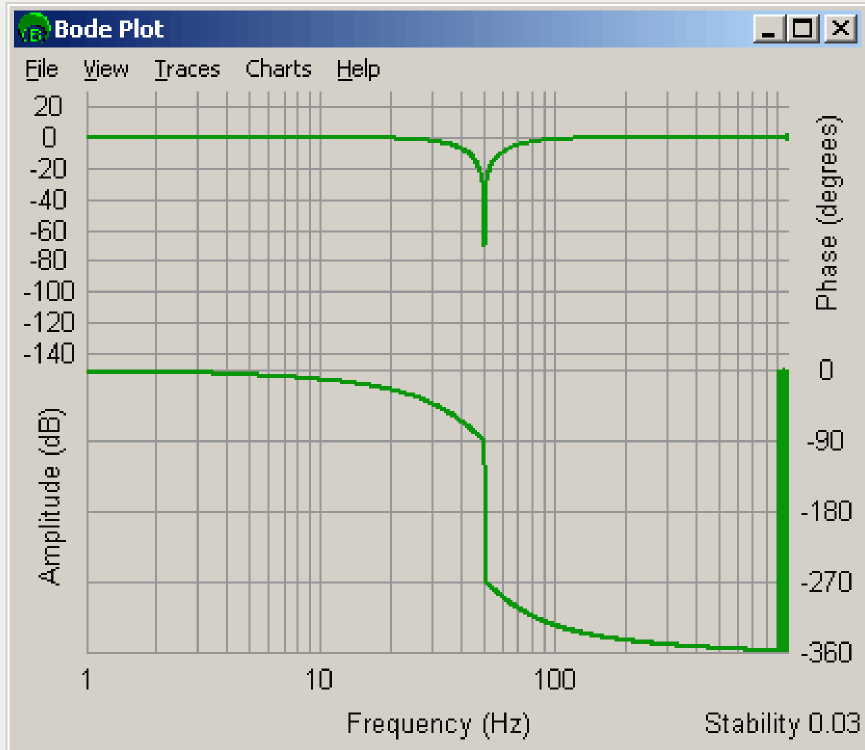
Postfilters are used to digitally filter the output of a control loop. One common use for postfilters is the compensation of system resonances.

type	The postfilter section type. This field determines which field of the MEIPostfilterSection.data union is used by meiFilterPostfilter…() methods. More information about particular filter types can be found below and in the MEIFilterType documentation.

form	The form of a postfilter section. The form determines how a particular postfilter section is calculated on the controller. All forms have certain limitations and tradeoffs. Please refer to MEIFilterForm for more information.
lowPass.breakpoint	The break point (measured in Hertz) of a low pass postfilter section.  Example of a 50 Hz low pass filter.
highPass.breakpoint	The break point (measured in Hertz) of a high pass postfilter section.  Example of a 50 Hz High pass filter

notch.centerFrequency

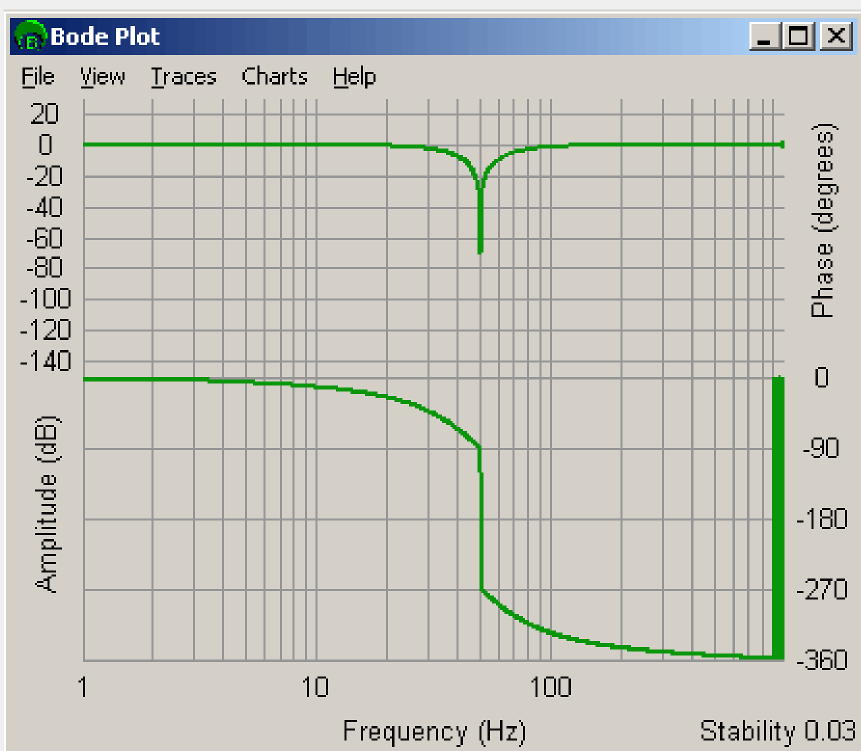
The bandwidth (measured in Hertz) of a notch postfilter section.



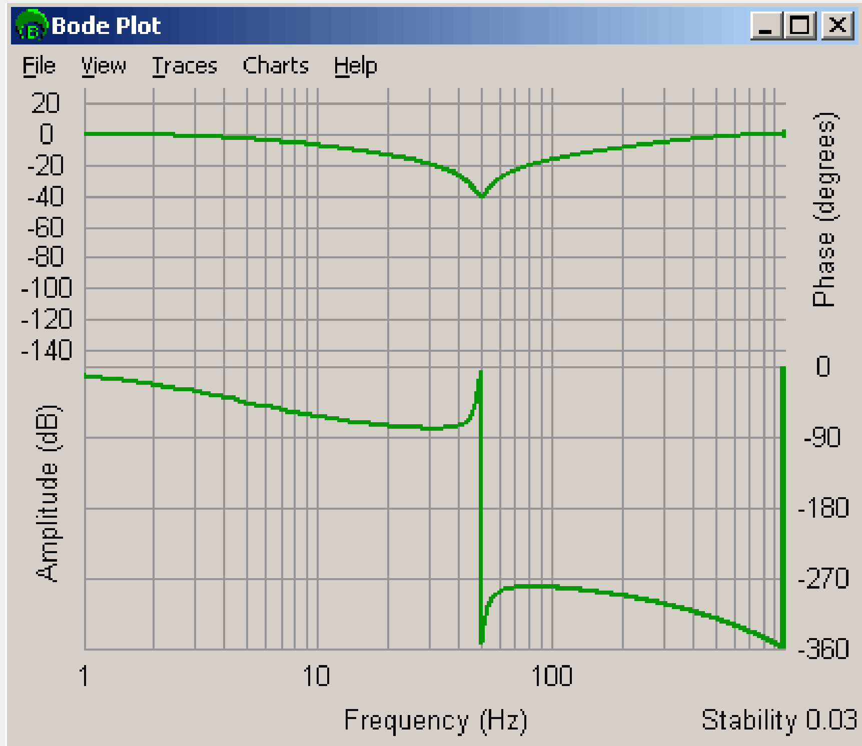
Example of a 50 Hz Center / 50 Hz Bandwidth Notch filter. Note that phase wrapping gives the illusion that phase drops 180 degrees after the center frequency. The phase raises by 180 degrees.

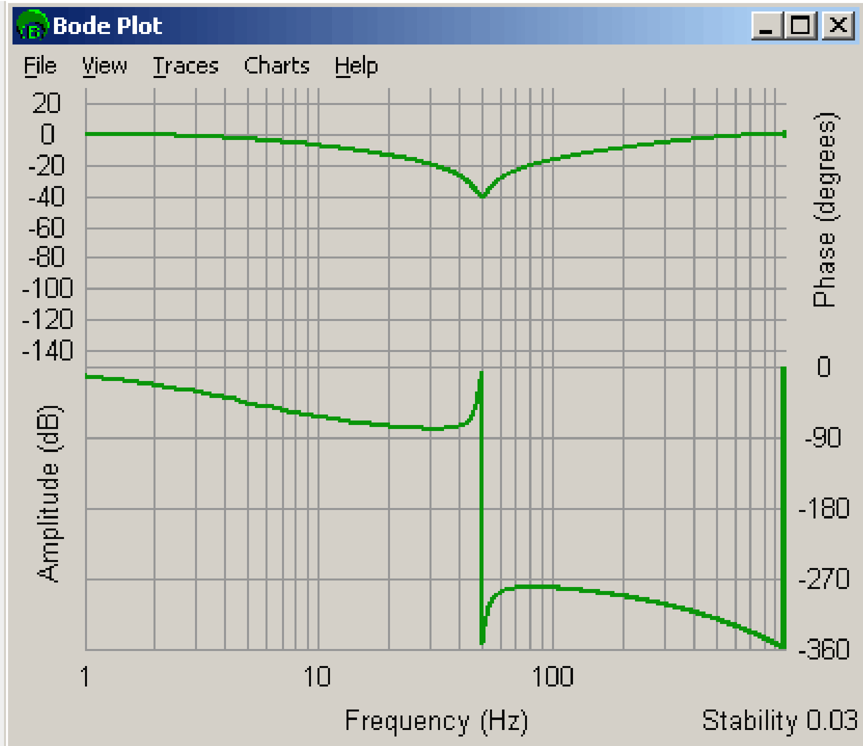
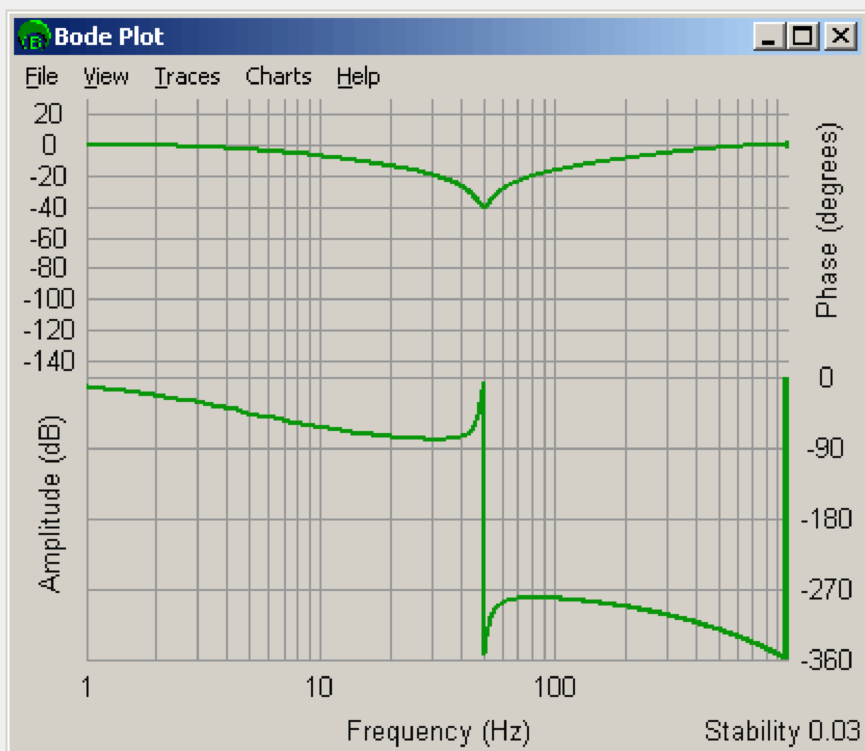
notch.bandwidth

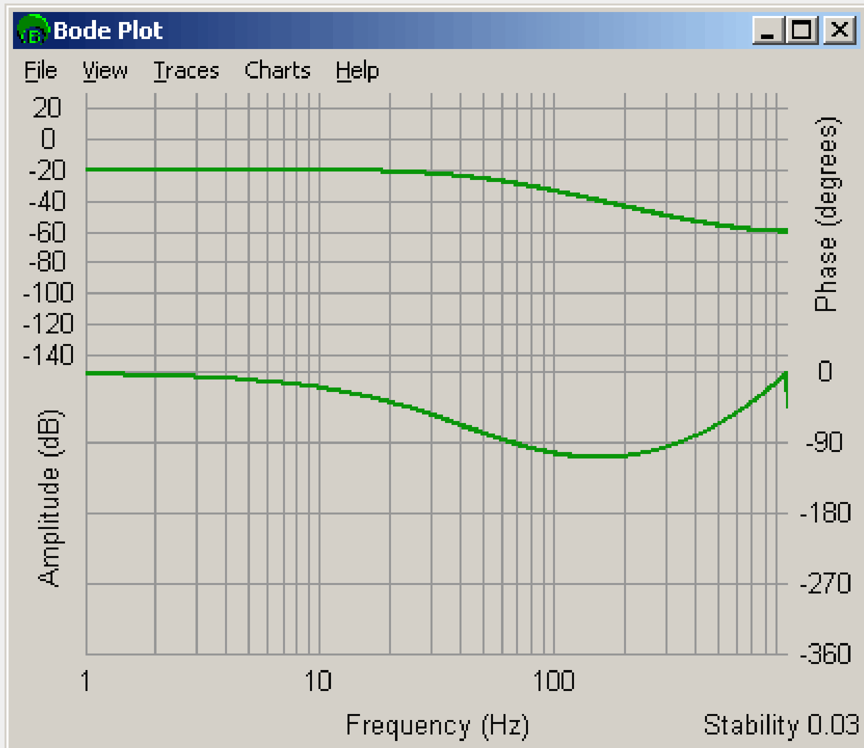
The center frequency (measured in Hertz) of a notch postfilter section.

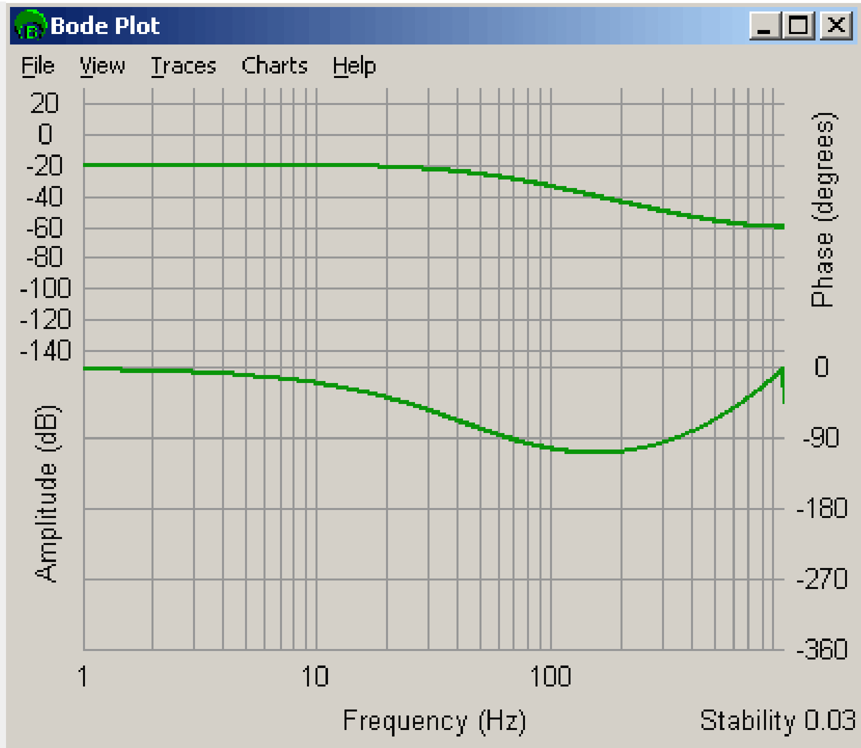
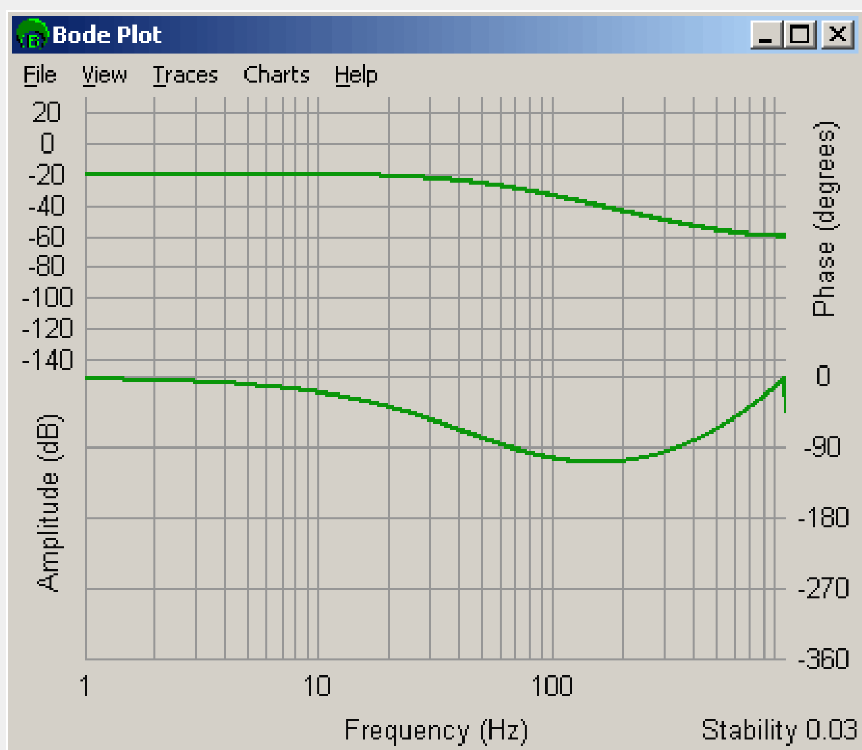


Example of a 50 Hz Center / 50 Hz Bandwidth Notch filter. Note that phase wrapping

	gives the illusion that phase drops 180 degrees after the center frequency. The phase raises by 180 degrees.
resonator.centerFrequency	The center frequency (measured in Hertz) of a resonator postfilter section.  Example of a 50 Hz center / 50 Hz Bandwidth / -40 dB Gain Resonator filter. Note that phase wrapping gives the illusion that the phase drops 360 degrees after the center frequency.
resonator.bandwidth	The bandwidth (measured in Hertz) of a resonator postfilter section.

	 Example of a 50 Hz center / 50 Hz Bandwidth / -40 dB Gain Resonator filter. Note that phase wrapping gives the illusion that the phase drops 360 degrees after the center frequency.
resonator.gain	The center frequency gain (measured in dB) of a resonator postfilter section.  Example of a 50 Hz center / 50 Hz Bandwidth / -40 dB Gain Resonator filter. Note that phase wrapping gives the illusion that the phase drops 360 degrees after the center frequency.

leadLad.centerFrequency	The center frequency (measured in Hertz) of a lead or lag postfilter section. The amplitude at this frequency is the average amplitude of the low and high frequency amplitudes. The gain (measured in dB) at this point is given by: $$centerFrequencyGain = 20 \cdot \log_{10}\left(\frac{10^{\frac{lowFrequencyGain}{20}} + 10^{\frac{highFrequencyGain}{20}}}{2}\right)$$  Example of a -20 dB low frequency gain / -60 dB high frequency gain / 50 Hz center lead lag filter.
leadLag.lowFrequencyGain	The low frequency gain (measured in dB) of a lead or lag postfilter section.

	 Example of a -20 dB low frequency gain / -60 dB high frequency gain / 50 Hz center lead lag filter.
leadLag.highFrequencyGain	The high frequency gain (measured in dB) of a lead or lag postfilter section.  Example of a -20 dB low frequency gain / -60 dB high frequency gain / 50 Hz center lead lag filter.

<table>
<tr><td>biquad.a1</td><td rowspan="5">The analog coefficients of a single order or bi-quad postfilter section.

Analog values of the postfilter coefficients are produced as parts of a Laplace Transform:

$$H(s) = \frac{b_0 + b_1 \cdot s + b_2 \cdot s^2}{1 + a_1 \cdot s + a_2 \cdot s^2} \text{ where } s = j \cdot \omega_{warped}$$
and

$$\omega_{warped} = 2 \cdot sampleRate \cdot \tan\left(\frac{\pi \cdot f}{sampleRate}\right)$$</td></tr>
<tr><td>biquad.a2</td></tr>
<tr><td>biquad.b0</td></tr>
<tr><td>biquad.b1</td></tr>
<tr><td>biquad.b2</td></tr>
<tr><td>digitalBiquad.a1</td><td rowspan="5">The digital coefficients of a single order or bi-quad postfilter section.</td></tr>
<tr><td>digitalBiquad.a2</td></tr>
<tr><td>digitalBiquad.b0</td></tr>
<tr><td>digitalBiquad.b1</td></tr>
<tr><td>digitalBiquad.b2</td></tr>
<tr><td>digitalBiquad.d1</td><td rowspan="6">The digital coefficients of a state-space bi-quad postfilter section.</td></tr>
<tr><td>digitalBiquad.c1</td></tr>
<tr><td>digitalBiquad.c2</td></tr>
<tr><td>digitalBiquad.a2</td></tr>
<tr><td>digitalBiquad.a1</td></tr>
<tr><td>digitalBiquad.b1</td></tr>
<tr><td>polesZeros.poleCount</td><td rowspan="4">Analog poles and zeros.</td></tr>
<tr><td>polesZeros.zeroCount</td></tr>
<tr><td>polesZeros.pole[].real</td></tr>
<tr><td>polesZeros.pole[].imag</td></tr>
<tr><td>digitalPolesZeros.poleCount</td><td rowspan="4">Digital poles and zeros.</td></tr>
<tr><td>digitalPolesZeros.zeroCount</td></tr>
<tr><td>digitalPolesZeros.pole[].real</td></tr>
<tr><td>digitalpolesZeros.pole[].imag</td></tr>
<tr><td>stateSpaceBiquad.d1</td><td rowspan="6">State space coefficients.</td></tr>
<tr><td>stateSpaceBiquad.c1</td></tr>
<tr><td>stateSpaceBiquad.c2</td></tr>
<tr><td>stateSpaceBiquad.a2</td></tr>
<tr><td>stateSpaceBiquad.a1</td></tr>
<tr><td>stateSpaceBiquad.b1</td></tr>
<tr><td>iir.numberOfCoefficients</td><td rowspan="2">Currently not supported. Reserved for future use.</td></tr>
<tr><td>iir.coeff</td></tr>
</table>

Sample Code

```
/*   Set a 4th order low-pass post-filter by using two 2nd order low-pass sections.
     Sample usage:

     returnValue =
         fourthOrderLowPass(filter, 300 /* Hz */);
*/
long filterFouthOrderLowpass(MPIFilter filter, long breakPointFrequency)
{
    MPIFilterConfig config;
    MEIPostfilterSection sections[2];
    long returnValue;

    section[0].type = MEIFilterTypeLOW_PASS;
    section[0].form = MEIFilterFormINT_BIQUAD;
    section[0].lowPass.breakpoint = breakPointFrequency;
    section[1] = section[0]; /* copy first section */

    returnValue =
        meiFilterPostfilterSet(filter, 2, sections);

    return returnValue;
}
```

See Also

MEIFilterType | MEIFilterForm | MEIMaxIIRCoefficients | meiFilterPostfilterGet | meiFilterPostfilterSet | meiFilterPostfilterSectionGet | meiFilterPostfilterSectionSet |

Post Filter Theory section.

MPIFilterCoeffCOUNT_MAX

MPIFilterCoeffCOUNT_MAX

```
#define MPIFilterCoeffCOUNT_MAX (20)
```

Description

FilterCoeffCOUNT_MAX is a constant that defines the maximum number of filter coefficients contained in a gain table.

See Also

MPIFilterCoeff

MPIFilterGainCOUNT_MAX

MPIFilterGainCOUNT_MAX

```
#define MPIFilterGainCOUNT_MAX (20)
```

Description

FilterGainCOUNT_MAX is a constant that defines the maximum number of filter gain tables. The first gain table is used by the standard filter types (all filter types except for the user filter type as defined by the structure MEIXmpAlgorithm). Additional gain tables can be used for manual or automatic gain switching. For firmware that implements automatic gain switching, please contact Motion Engineering. Manual gain switching can be accomplished by specifying the gainIndex of the mpiFilterConfig structure using the mpiFilterConfigSet method. Valid gainIndex values range from 0 to MPIFilterGainCOUNT_MAX.

See Also

MPIFilterGain

MEIMaxBiQuadSections

MEIMaxBiQuadSections

```
#define MEIMaxBiQuadSections  (6)
```

Description

MEIMaxBiQuadSections is the maximum number of Bi-Quad sections a postfilter can use.

NOTE: The PIV algorithm uses the last Bi-Quad section internally. Thus a user can only use (MEIMaxBiQuadSections - 1) Bi-quad sections with the PIV algorithm.

See Also

MEIPostFilterSection | meiFilterPostfilterGet | meiFilterPostfilterSet | meiFilterPostfilterSectionGet | meiFilterPostfilterSectionSet

Special Note: *High / Low Output Limits (MEIFilterGainPID and PIV)*

In the 19990820 release, the MEIFilterGainPID and MEIFilterGainPIV structures were expanded to support High and Low output limits for PID and PIV algorithms. The "High" output limit prevents the filter output from exceeding the "High" value. The "Low" output limit prevents the filter output from falling below the "Low" value. This feature will allow an application to have upper and lower limits which are not centered on zero volts. If the "High" and "Low" values have the same sign, then the output will be limited to either the positive or negative range bounded by "High" and "Low".

The standard Output Limit is still valid. The controller will simultaneously use the standard Output Limit and the High / Low Output Limits to bound the output. The limits, (standard or high or low) that are closest to zero will be used as the boundary for the output.

Return to MEIFilterGainPID or MEIFilterGainPIV

Post Filter Theory

Laplacian Space | Z Space | Z Transform Stability

Laplacian Space

Analog values of the postfilter coefficients are produced as parts of a Laplace Transform:

$$H(s) = \frac{b_0 + b_1 \cdot s^{-1} + b_2 \cdot s^{-2}}{1 + a_1 \cdot s^{-1} + a_2 \cdot s^{-2}} \text{ where } s = j \cdot \omega_{warped}$$

and

$$\omega_{warped} = 2 \cdot sampleRate \cdot \tan\left(\frac{\pi \cdot f}{sampleRate}\right)$$

The amplitude and phase of the filter can be derived from the above by:

$$A^2 = \frac{\left(b_2 - b_0\omega^2\right)^2 + \left(b_1\omega\right)^2}{\left(a_2 - \omega^2\right)^2 + \left(a_1\omega\right)^2}$$

$$phase = \arctan2\left(\left[\left(b_2 - b_0\omega^2\right)\left(a_2 - \omega^2\right) + a_1 b_1 \omega^2\right],\ \omega\left[b_1\left(a_2 - \omega^2\right) - a_1\left(b_2 - b_0\omega^2\right)\right]\right)$$

$\arctan2(x, y)$ is similar to $\arctan\left(\frac{y}{x}\right)$ except that the returned angle can be in the range from $-\pi$ to π.

From here we can calculate the gain (in dB) of the filter:

$$gain = 10 \cdot \log_{10}\left(\frac{\left(b_2 - b_0\omega^2\right)^2 + \left(b_1\omega\right)^2}{\left(a_2 - \omega^2\right)^2 + \left(a_1\omega\right)^2}\right)$$

The filter types are designed as follows:

Low Pass	$\Omega = 2 \cdot sampleRate \cdot \tan\left(\frac{\pi \cdot f_{breakPt}}{sampleRate}\right)$ $a_1 = \sqrt{2} \cdot \Omega$ $a_2 = \Omega^2$ $b_0 = 0$ $b_1 = 0$ $b_2 = \Omega^2$
High Pass	$\Omega = 2 \cdot sampleRate \cdot \tan\left(\frac{\pi \cdot f_{breakPt}}{sampleRate}\right)$ $a_1 = \sqrt{2} \cdot \Omega$ $a_2 = \Omega^2$ $b_0 = -1$ $b_1 = 0$ $b_2 = 0$
Notch	$\Omega = 2 \cdot sampleRate \cdot \tan\left(\frac{\pi \cdot f_{breakPt}}{sampleRate}\right)$ $a_1 = 2 \cdot \pi \cdot bandwidth \cdot \left(1 + \tan^2\left(\frac{\pi \cdot f_{center}}{sampleRate}\right)\right)$ $a_2 = \Omega^2$ $b_0 = 1$ $b_1 = 0$ $b_2 = \Omega^2$
Resonator	$\Omega = 2 \cdot sampleRate \cdot \tan\left(\frac{\pi \cdot f_{center}}{sampleRate}\right)$ $a_1 = 2 \cdot \pi \cdot bandwidth \cdot \left(1 + \tan^2\left(\frac{\pi \cdot f_{center}}{sampleRate}\right)\right) \Big/ 10^{\left(\frac{gain}{40}\right)}$ $a_2 = \Omega^2$ $b_0 = 1$ $b_1 = a_1 \cdot 10^{\left(\frac{gain}{20}\right)}$ $b_2 = \Omega^2$

Lead, Lag	$\Omega = 2 \cdot sampleRate \cdot \tan\left(\frac{\pi \cdot f_{center}}{sampleRate}\right)$ $a_1 = 2 \cdot \Omega$ $a_2 = \Omega^2$ $b_0 = 10^{\left(\frac{highFrequencyGain}{20}\right)}$ $b_1 = 2 \cdot \Omega \cdot 10^{\left(\frac{lowFrequencyGain + highFrequencyGain}{40}\right)}$ $b_2 = \Omega^2 \cdot 10^{\left(\frac{lowFrequencyGain}{20}\right)}$

Additional Notes:

For the resonator filter, the maximum and minimum phase changes will occur at:

$$f = \frac{SampleRate}{\pi} \tan^{-1}\left(\frac{1}{2\sqrt{2} \cdot SampleRate} \sqrt{(a_1 b_1 - 2a_2) \pm \sqrt{a_1 b_1 (4a_2 + a_1 b_1)}}\right)$$

These frequencies also happen to be the half-gain points measured in dB (or the root-amplitude gain points).

For the lead/lag filters, the maximal phase change will occur at:

$$f = \frac{SampleRate}{\pi} \tan^{-1}\left(\frac{a_1}{4 \cdot SampleRate} \cdot \sqrt[4]{\frac{b_2}{a_2 b_0}}\right)$$

This frequency also happens to be the dB gain mean point measured (or the amplitude gain geometric mean point).

Z Space

Though Laplacian Space is useful for designing or quickly analyzing a bi-quad filter's design, it does not accurately model digital bi-quad filters. Digital filters are described naturally by Z transforms. It is possible to convert a filter from a Laplace transform to a Z transform, as will be described below, while maintaining the same general characteristics. The amplitude and phase information will be slightly warped by moving into Z space. One should note, however, that for the filters listed above the characteristics of gains, bandwidths, and center or breakpoint frequencies are unchanged.

Bi-quad filters are described by the following Z transform:

$$H(Z) = \frac{B_0 + B_1 \cdot Z^{-1} + B_2 \cdot Z^{-2}}{1 + A_1 \cdot Z^{-1} + A_2 \cdot Z^{-2}} \quad \text{where } Z = e^{j\left(\frac{2\cdot\pi\cdot f}{sampleRate}\right)}$$

One should note that only filters where the roots of the denominator lie within the unit circle are stable. Though digital filters can be constructed where the equations for amplitude and phase for both the Z transform version and the Laplace transform version may converge, the filter itself will be unstable, continually adding energy to the system. Please see the Z Transform Stability Section below.

The equations for amplitude, phase and dB gain can be derived from the above Z transform:

$$A^2 = \frac{\left(B_0^2 + B_1^2 + B_2^2\right) + 2\cdot B_1\cdot\left(B_0 + B_2\right)\cdot\cos\left(\frac{2\cdot\pi\cdot f}{sampleRate}\right) + 2\cdot B_0\cdot B_2\cdot\cos\left(\frac{4\cdot\pi\cdot f}{sampleRate}\right)}{\left(1 + A_1^2 + A_2^2\right) + 2\cdot A_1\cdot\left(1 + A_2\right)\cdot\cos\left(\frac{2\cdot\pi\cdot f}{sampleRate}\right) + 2\cdot A_2\cdot\cos\left(\frac{4\cdot\pi\cdot f}{sampleRate}\right)}$$

$$phase = \operatorname{arctan2}\left(\left(\begin{array}{l}\left(B_0 + A_1\cdot B_1 + A_2\cdot B_2\right) + \left(A_1\cdot B_0 + B_1 + A_2\cdot B_1 + A_1\cdot B_2\right)\cdot\cos\left(\frac{2\cdot\pi\cdot f}{sampleRate}\right) + \\ \qquad \left(B_0\cdot A_2 + B_2\right)\cdot\cos\left(\frac{4\cdot\pi\cdot f}{sampleRate}\right)\end{array}\right), \left(A_1\cdot B_0 - B_1 + A_2\cdot B_1 - A_1\cdot B_2\right)\cdot\sin\left(\frac{2\cdot\pi\cdot f}{sampleRate}\right) + \left(B_0\cdot A_2 - B_2\right)\cdot\sin\left(\frac{4\cdot\pi\cdot f}{sampleRate}\right)\right)$$

$$gain = 10\cdot\log_{10}\left(\frac{\left(B_0^2 + B_1^2 + B_2^2\right) + 2\cdot B_1\cdot\left(B_0 + B_2\right)\cdot\cos\left(\frac{2\cdot\pi\cdot f}{sampleRate}\right) + 2\cdot B_0\cdot B_2\cdot\cos\left(\frac{4\cdot\pi\cdot f}{sampleRate}\right)}{\left(1 + A_1^2 + A_2^2\right) + 2\cdot A_1\cdot\left(1 + A_2\right)\cdot\cos\left(\frac{2\cdot\pi\cdot f}{sampleRate}\right) + 2\cdot A_2\cdot\cos\left(\frac{4\cdot\pi\cdot f}{sampleRate}\right)}\right)$$

The equations for converting between the analog (Laplace transform) coefficients and the digital (Z transform) coefficients are handled internally by the MPI, but are listed below so that one can accurately analyze the performance of the bi-quad filters.

Bi-quad Postfilter	**Bi-linear Postfilter ($a_2 = b_2 = 0$)**
$D = 4 + \frac{2 \cdot a_1}{sampleRate} + \frac{a_2}{sampleRate^2}$	$D = \frac{2 \cdot a_1}{sampleRate}$
$A_1 = \frac{\left(\frac{2 \cdot a_2}{sampleRate^2} - 8\right)}{D}$	$A_1 = \frac{\left(\frac{a_1}{sampleRate} - 2\right)}{D}$
$A_2 = \frac{\left(4 - \frac{2 \cdot a_1}{sampleRate} + \frac{a_2}{sampleRate^2}\right)}{D}$	$A_2 = 0$
$B_0 = \frac{\left(4 \cdot b_0 + \frac{2 \cdot b_1}{sampleRate} + \frac{b_2}{sampleRate^2}\right)}{D}$	$B_0 = \frac{\left(\frac{b_1}{sampleRate} + 2 \cdot b_0\right)}{D}$
$B_1 = \frac{\left(\frac{2 \cdot b_2}{sampleRate^2} - 8 \cdot b_0\right)}{D}$	$B_1 = \frac{\left(\frac{b_1}{sampleRate} - 2 \cdot b_0\right)}{D}$
$B_2 = \frac{\left(4 \cdot b_0 - \frac{2 \cdot b_1}{sampleRate} + \frac{b_2}{sampleRate^2}\right)}{D}$	$B_2 = 0$

Z Transform Stability

As briefly described in the last section, it is possible for the digital filters constructed from analog filters to be unstable. One needs to ensure that:

- The filter does not continually add energy to a system.
- The filter has no phase lag at 0 frequency. (A filter with 180° phase lag will create unstable closed loop systems.)

To guarantee a filter does not continually add energy to a system, the following relationship must be satisfied by the Z transform coefficients:

$$\left|\frac{A_1}{2} \pm \sqrt{\frac{A_1^2}{2} - A_2}\right| < 1$$

To guarantee a filter has no phase lag at 0 frequency, the following relationship must be satisfied by the Z transform coefficients:

$$\left(1 + A_1 + A_2\right) \cdot \left(B_0 + B_1 + B_2\right) \geq 0$$

If it is found that this last condition is not true, then one should change the sign on all B_n coefficients. Equivalently, one can change the sign of all b_n coefficients for the Laplace (analog) transform.

Return to Filter Objects