Nonlinear RF Signal Support

Diode curve linearization

Mon, Sep 9, 2002

Formulas are used to linearize RF gradient and power readings, replacing the readings measured across a diode so the replacing value can be linearly scaled to engineering units. One formula is used for RF gradients (amplitude), and the other is used for RF powers.

RF diodes usually have a nonlinear characteristic in the low range, because the diode doesn't conduct until the RF waveform's amplitude reaches a few tenths of a volts. For RF gradients, where we measure the RF amplitude, the diode performance is usually linear beyond a certain threshold. We may approximate the range below that threshold with a straight line so that the reading approaches zero as the RF amplitude goes to zero. The formula used for these signals is as follows:

> Define a constant voltage `k`.
> Assume the A/D reading of an RF gradient is `v`.
> Assume the resultant gradient value is `g`.
> Then for `v < k`, and for `v > k`,
> `g = 2v — k` `g = v`

RF powers are like the square of the gradient. If we approximate the gradient with a square root function in the low range—rather than the straight line to the origin used above—we can use a linear approximation for the power in the low range and a quadratic in the high range. The formula used for RF powers is as follows:

> Define a constant voltage `k`.
> Assume the A/D reading of an RF power is `v`.
> Assume the resultant power value is `p` (in linearized volts).
> Then for `v < k`, and for `v > k`,
> `p = v` `p = (v+k)^2/(4k)`

Because the RF powers linearization formula is quadratic, the value of `p` can easily exceed 10 volts, given a high enough `v`. But the result of the linearization replaces the reading value, which is a 16-bit field that corresponds to a ±10 volt range. The RF power linearized reading is subsequently scaled to engineering units linearly, as are all analog signals. This common scaling formula is the following, where `e`= the engineering units result value, `r` is the reading voltage, `f`= fullscale, and `o`= offset:

```
e = (r/10)f + o
```

(For these RF signals, the linearized value of `g` or `p` in the preceding section is used as `r`.)
The fraction of fullscale (10 volts) is multiplied by the fullscale value and the offset is added. In this formulation, both the `f` and the `o` values are in engineering units.

In order to have some control over the linearized reading value range in the RF powers case, an additional constant factor can be used in the formula. It is expressed as a power of two. Call the constant value `c = 2^n`. If we replace `v`, `k`, and `f` in the following way, the formula results in the same final engineering units value, while allowing for not exceeding the 10 volt range of the intermediate linearized reading:

```
v' = vc
k' = kc
f' = f/c
```

Note that for `c < 1` (or `n < 0`), the value for `p` can be reduced so as not to exceed 10 volts. But the value for `e` is maintained by the compensating change in f. One should take care not to choose too small a value for `c`, or the resolution at low power levels may suffer.

The fullscale value `f'` is entered in the analog descriptor as the A/D fullscale. The *unshifted* constant `k` is entered as the D/A offset value. (Such linearized channels cannot have settings for this reason. They *can* have motor control, however; in that case, the D/A fullscale value is used for the number of steps per 10-volt reading change.)

The following entry in the data access table specifies RF signal linearizations:

0 6 0 0	chan	memPtr	
sign	shift	mStep	count

The *chan* value is the initial channel to be linearized. The *memPtr*, if nonzero, is an optional pointer to a memory word, rather than taking the input from the reading word of the channel being linearized. The *mStep* is only used with the *memPtr* option to specify the #bytes step between successive words to be linearized. The *shift* count is an exponent value `n` above, applied to the channel range. (For example, shift= `$FFFD` for `n`=–3.) The *sign* word is `$8000` to specify that the source words are expected to be negative values, and `$0000` otherwise. The *count* defines the range of channels scanned. Note that the byte mask of 08 must be used in the analog descriptor CONV field for each channel in the range that is to be linearized. Channels without this mask are skipped. Channels with that bit set use byte mask `01` to specify power linearization, else the gradient formula is used. (Use `08` for gradients, `09` for powers.)