Measurement noise in 120A DCCTs in the LHC

SY/EPC/HPM/ Miguel Bastos

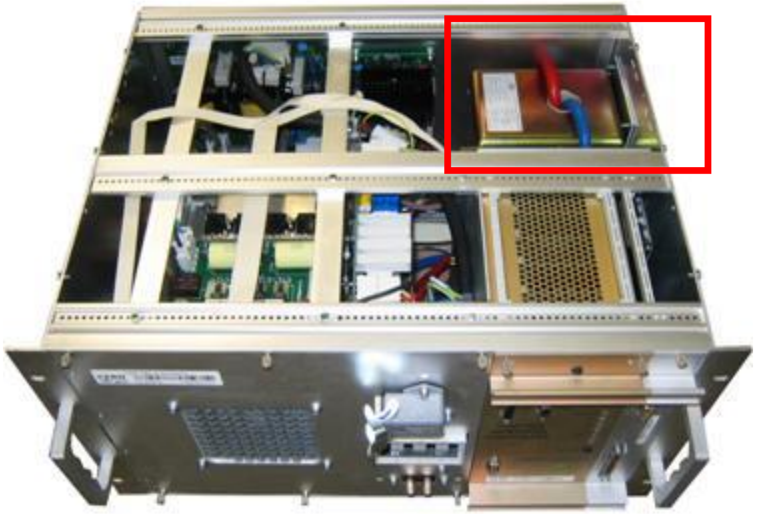
28.02.2023

The 120A LHC DCCTs

- The 120A LHC DCCTs are bipolar Direct Current Current Transducers (DCCTs) with a nominal current of 120A
- They are used in the 60A and 120A orbit corrector power Converters (1504 and 580 units, respectively)
- Two models of 120A DCCTs used in the LHC:
  - 120A EMVI 401ED from Ritz
  - 120A MACC+ from Hitec (only 92 units, installed in the 60A converters

120A EMVI 401ED

120A MACC+
92 units in the
60A converters



Example of EMVI DCCT inside a 60A corrector

Introduction

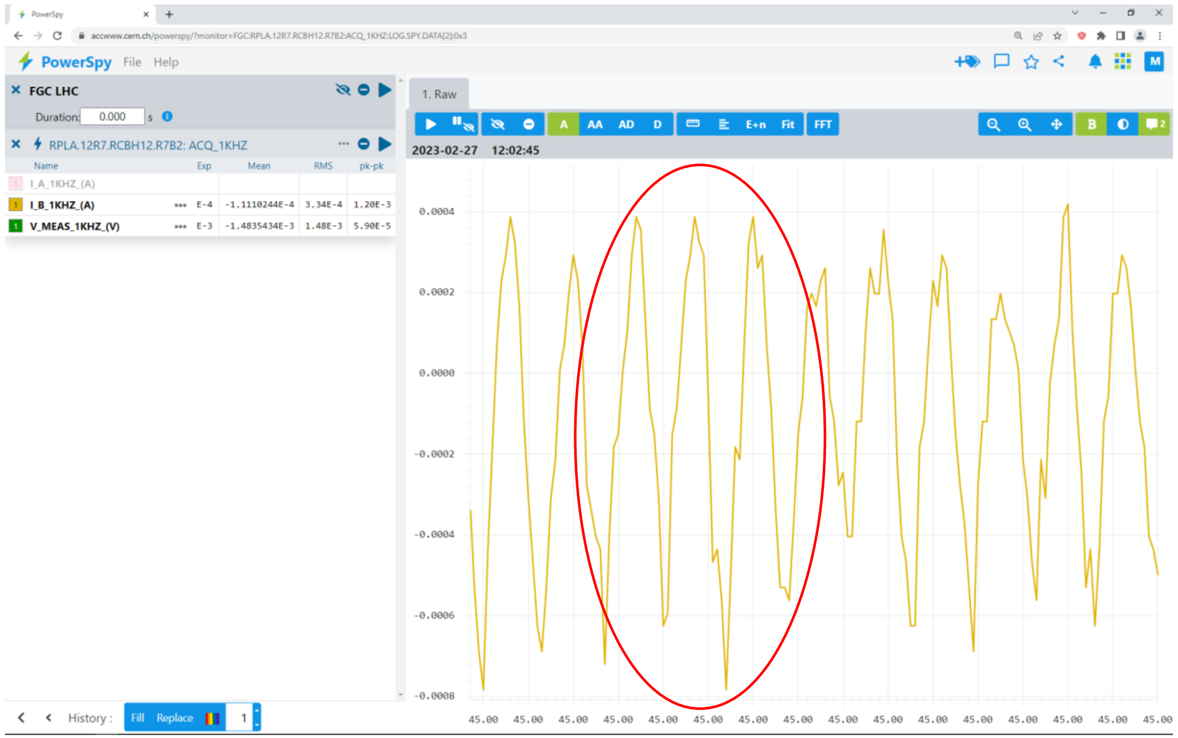
- The 120A LHC DCCTs are HL-LHC Accuracy Class 4 DCCTs
- Maximum noise in a 500Hz bandwidth is specified at ~45ppm pkpk

	Class 4			
	FGCLITE-INT-D4			
	FGC2.1-INT-TC-D4			
	FGC3.2-INT-D4			
	total PC	**dcct**	**adc**	**notes**
Resolution [ppm]	1.0		0.2	
Initial uncertainty after cal [2xrms ppm] normal	10.0	8.0	2.0	sum of rms
Linearity [ppm] [max abs ppm] uniform	9.0	5.0	4.0	sum of max
Stability during a fill (12h) [max abs ppm] uniform	9.5	6.0	3.5	sum of max
Short term stability (20min) [2xrms ppm] normal	5.0	4.0	1.0	sum of rms
Noise (<500Hz) [2xrms ppm] normal	19.0	15.0	4.0	sum of rms
Fill to fill repeatability [2xrms ppm] normal	5.0	3.0	2.0	sum of rms
Long term fill to fill stability [max abs ppm] uniform	45.0	30.0	15.0	sum of max
Temperature coefficient [max abs ppm/C] uniform	6.5	3.0	3.5	sum of max

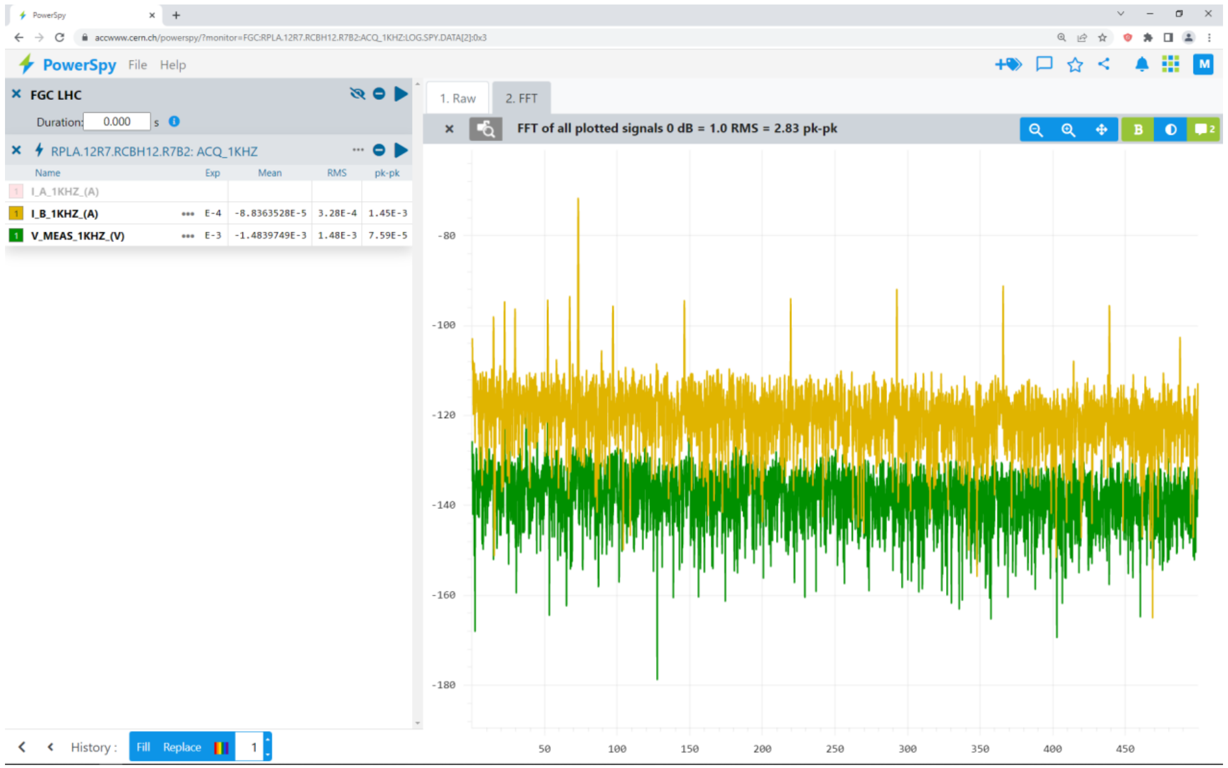
Table 16: HL-LHC accuracy class 4

The 120A DCCT

- The Ritz and MACC+ DCCTs have a modulation frequency of **70Hz,** also present on its output, normally in the order of a few ppm,
- **However** some Ritz DCCTs have developed an excess of modulation noise,
- In the worst case a noise of **100ppm pkpk** was measured in 2017, the average of all 60A was **16ppm pkpk,**
- A repair campaign of the worst 60 units was carried out during LS2. Worst case noise after repair was **30ppm pkpk** (measured in the lab).

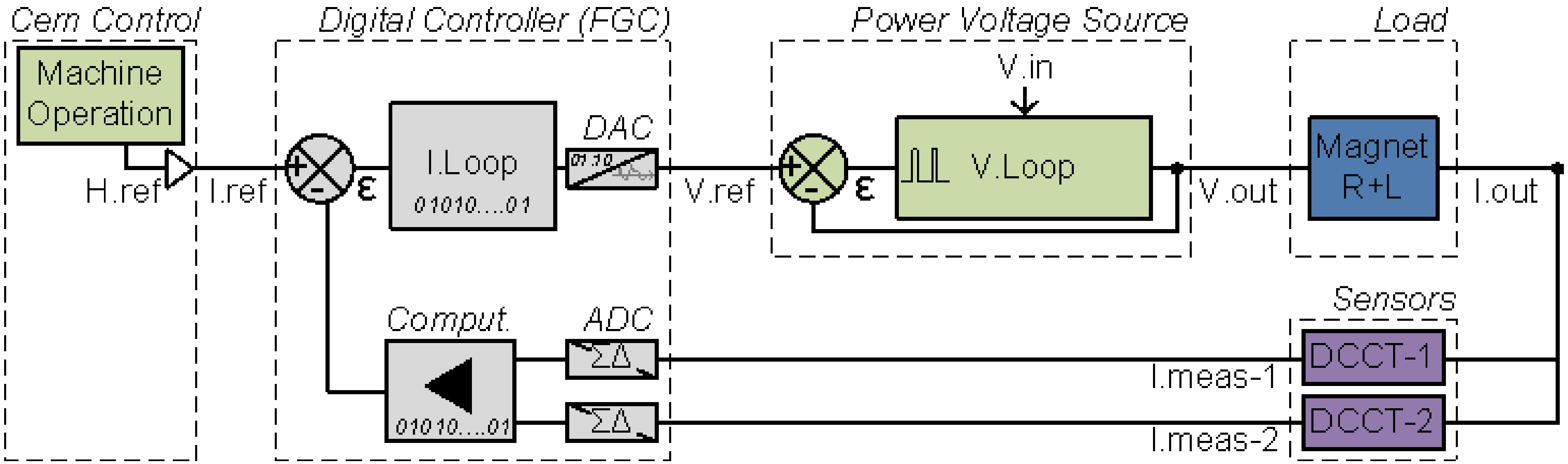


example at 20pm pkpk
after repair



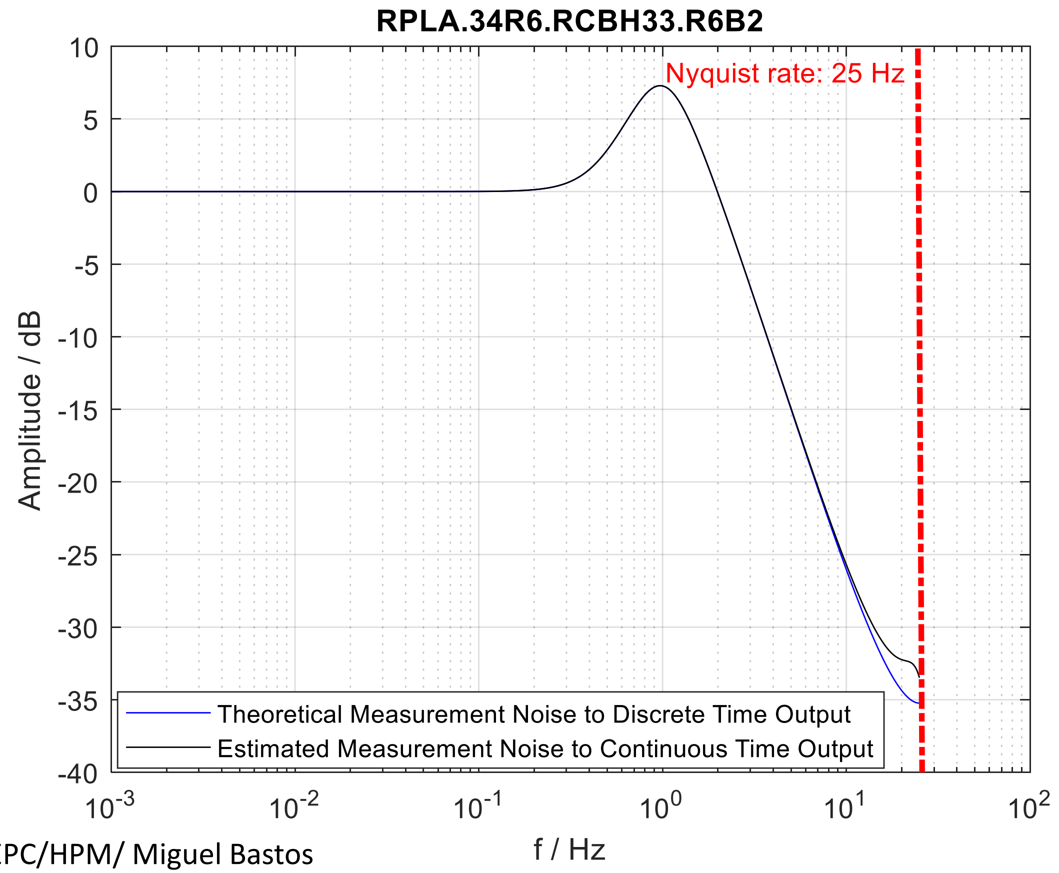
The current regulation loop

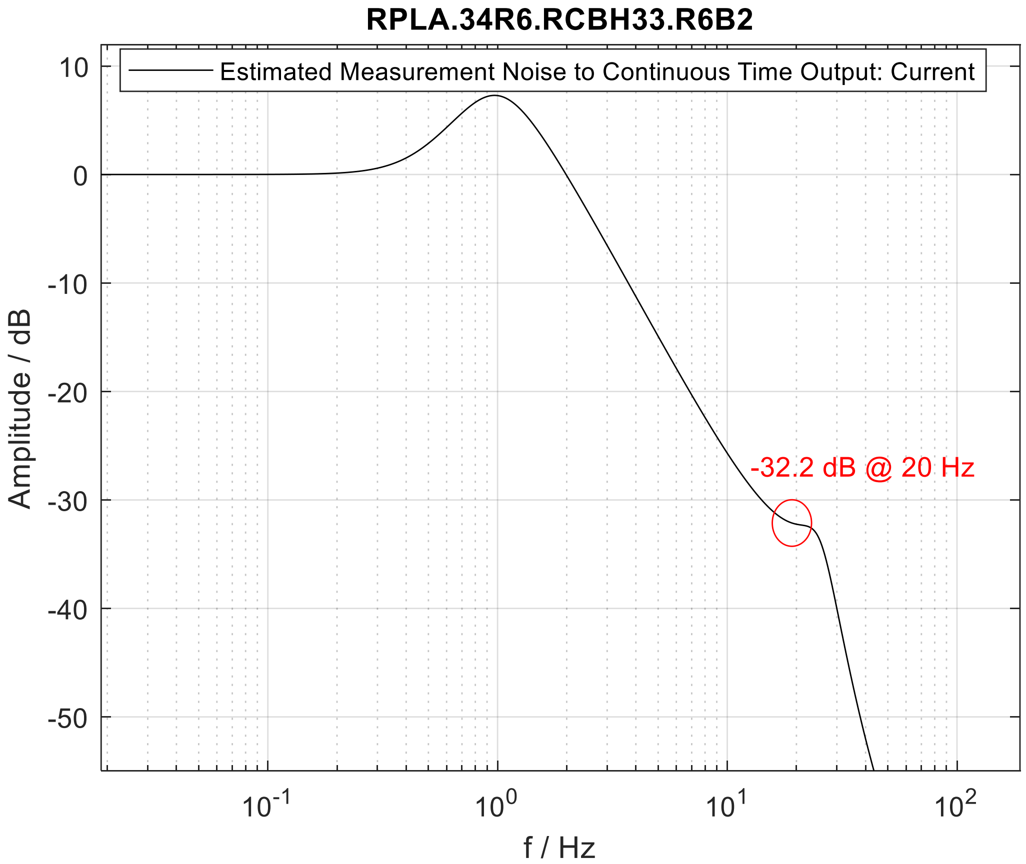
- The DCCT output is sampled by an ADC and used in a closed loop to produce the magnet current
- How the loop responds to the noise defines how much of the modulation noise is transformed in current noise
- The regulation in the FGCLite is carried out in the gateway and therefore the current measured is sampled at the worldFIP link speed of 50Hz, **so the 70Hz noise is aliased down to 20Hz**
- Access to non real time 1kHz acquisitions is still possible for diagnostics



The current regulation loop

- The sensitivity function below shows the relationship between measurement noise and output current
- At the aliased frequency of 20Hz, an attenuation of **-32dB** is expected due to the very high inductance of the load and the corresponding very low BW of the current loop
- For the worst case of 30ppm pkpk, a noise of **<1ppm pkpk** is expected in the magnet current (spec for class 4 is **45ppm pkpk**)

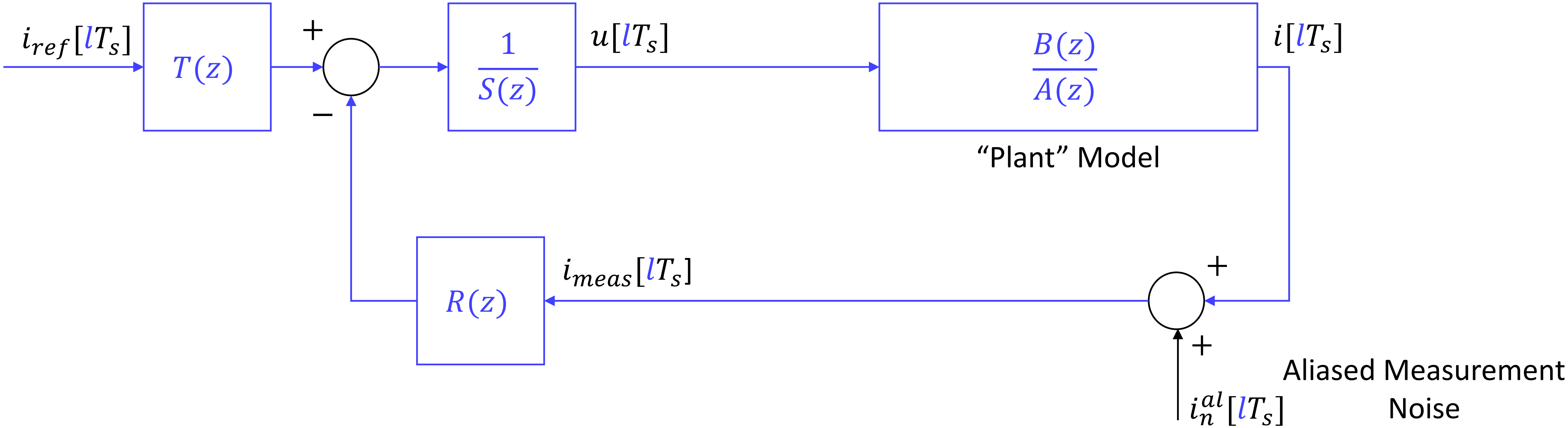




The current regulation loop

Further considerations

Discrete Time Modelling: $T_s = 20\ \text{ms}$

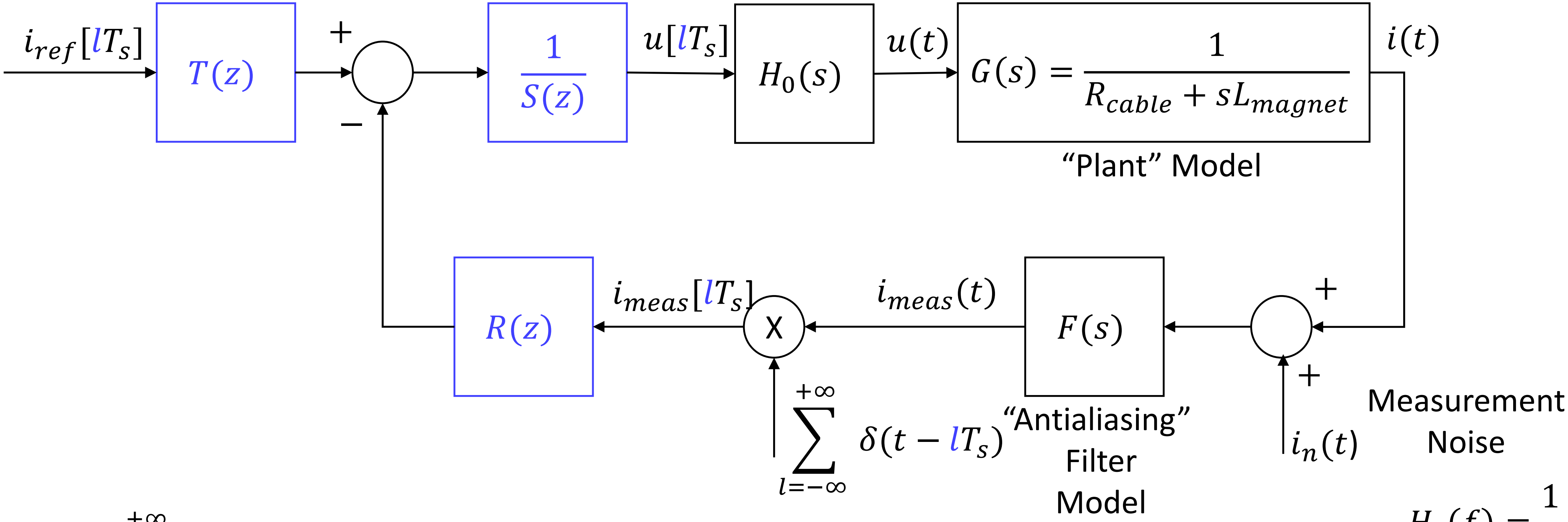


$$I[e^{j2\pi fT_s}] = -\frac{R[e^{j2\pi fT_s}]}{S[e^{j2\pi fT_s}]}\mathcal{S}_o[e^{j2\pi fT_s}]I_n^{al}[e^{j2\pi fT_s}]$$

$$\mathcal{S}_0[e^{j2\pi fT_s}] = \frac{1}{1 + \frac{R[e^{j2\pi fT_s}]}{S[e^{j2\pi fT_s}]}\frac{B[e^{j2\pi fT_s}]}{A[e^{j2\pi fT_s}]}}$$

Only valid up to Nyquist frequency : 25 Hz

Simplified Hybrid Modelling: $T_s = 20\ \mathrm{ms}$



$$H_0(f) = \frac{1 - e^{j2\pi f T_s}}{j2\pi f T_s}$$

$$I(f) = -P(f) \sum_{k=-\infty}^{+\infty} F\left(f - \frac{k}{T_s}\right) I_n\left(f - \frac{k}{T_s}\right)$$

$$S[e^{j2\pi f T_s}] = \frac{1}{1 + \frac{R[e^{j2\pi f T_s}]}{S[e^{j2\pi f T_s}]} \Lambda[e^{j2\pi f T_s}]}$$

$$P(f) = \frac{R[e^{j2\pi f T_s}]}{S[e^{j2\pi f T_s}]} H_0(f) G(f) \mathcal{S}[e^{j2\pi f T_s}]$$

$$\Lambda[e^{j2\pi f T_s}] = \sum_{k=-\infty}^{+\infty} F\left(f - \frac{k}{T_s}\right) G\left(f - \frac{k}{T_s}\right) H_0\left(f - \frac{k}{T_s}\right)$$