Fermilab

$\bar{p}$ Note #279

Search Coils and Integrator
Noise and Drift

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P NOTE

" SEARCH COILS &

INTEGRATOR

NOISE & DRIFT "

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SEARCH COILS & INTEGRATOR DRIFT

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INTRO : N2 Plan on MEASURING
 $\int B^2 dl$ ~~(A)~~ $\int B dl$ ACROSS THE APERTURE
FOR TEV 1 QUADS & DIPOLES TO
BETTER THAN 1 PART/10⁴. THE
FLAT COILS WERE DESIGNED TO BE
ABLE TO DO THIS.

I. INTEGRATOR NOISE :

THE OUTPUT OF THE INTEGRATORS

$$V_0 = \frac{1}{R_{IN}} \left\{ \int V_{IN}(\omega) + N * d * s * \Delta \int B^2 dl \right\}$$

FOR THE QUADRIPOLE GRADIENT COILS.

- R_i - INTEGRATOR INPUT IMPEDANCE (EXTERNAL)
- V_{IN} - INTEGRATOR INPUT NOISE
- N - # TURNS ON SEARCH COIL
- d - COIL WIDTH
- s - COIL PAIR SEPARATION (CTR to CTR)

TO RESOLVE A $\frac{AB'}{B'} = \frac{1}{10^4}$

$$\int_0^{t_1} V_{i,N}(t) dt \ll N * C * d * 10^{-4} \int B' dl$$

WHERE t_1 IS THE TIME IT TAKES TO MAKE A MEASUREMENT.

MEASUREMENTS WILL TAKE APPROXIMATELY 60A, FOR THREE PASSES ACROSS THE MAGNET APERTURE. THE 3 PASSES ALLOW THE COMPUTER TO CORRECT FOR LINEAR AND QUADRATIC INTEGRATOR DRIFT.

THESE MEASUREMENTS WERE SIMULATED USING GRADIENT COILS AND AN MTF INTEGRATOR WITH AN AD243L OP-AMP. THE RESIDUAL DRIFT, AFTER LINEAR AND QUADRATIC CORRECTIONS, WAS FOUND TO BE $\approx \frac{1}{RL} 0.43 \mu V$. $\left\{ \begin{array}{l} \text{TOTAL} \\ \text{DRIFT} \end{array} \right\}$

IN FOOTNOTE #1, THIS IS SHOWN TO BE APPROXIMATELY WHAT ONE EXPECTS CONSIDERING

THE OP-AMP INPUT NOISE.

SINCE THE OUTPUT NOISE IS PROPORTIONAL TO THE INTEGRATOR GAIN,* THE SIGNAL TO NOISE RATIO FOR MEASURING A MAGNET IS INDEPENDENT OF THE INTEGRATOR GAIN. THE GEOMETRY OF THE COIL MUST BE CHOSEN TO GIVE A GOOD SIGNAL TO NOISE RATIO, AND TO HAVE AS LITTLE RESPONSE AS POSSIBLE TO HIGHER-POLE MAGNETIC FIELDS.

THE QUADRAPOLE COILS WERE DESIGNED TO HAVE NO RESPONSE TO OCTAPOLE FIELDS, AND THE DIPOLE COILS TO HAVE NO RESPONSE TO SEXTAPOLE FIELDS.

THERE ARE 5 TYPES OF PROBES BEING BUILT. TABLE ONE LISTS THE SIGNAL TO NOISE RATIOS FOR THESE PROBES.

* FOR OUR COIL IMPEDANCES INPUT VOLTAGE NOISE (NOT CURRENT NOISE) IS IMPORTANT.

TABLE 1:

PROBE TYPE	SIGNAL TO NOISE RATIO FOR MEASURING 1 PART/10 ⁴
• SMALL APERTURE QUAD	6 - 18*
• LARGE APERTURE QUAD	24 - 41*
• LARGE APERTURE DIPOLE	50 - 155*
• SMALL APERTURE DIPOLE	

* THE SIGNAL TO NOISE RATIOS
VARY DEPENDING UPON THE
MAGNET LENGTH.

WE ATTEMPTED TO REDUCE TO INTEGRATOR
S/N RATIO BY ADD AN OP-27
PREAMP (SLIGHTLY BETTER NOISE
SPECS). FOR THE INPUT IMPEDANCES
USED FOR OUR TEST COILS, HOWEVER,
THE OP-27 HAD WORSE NOISE
CHARACTERISTICS.

THE SEARCH COILS WERE DESIGNED
AROUND THE MEASURED INTEGRATOR
NOISE FIGURES.

IN SUMMARY, THE S/N RATIO IS
INDEPENDENT OF INPUT RESISTANCE.
IT IS ALSO NOT EFFECTED BY
AMPLIFYING THE INTEGRATOR
OUTPUT.

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FOOTNOTE #1: OUTPUT NOISE DUE TO
OP-AMP (AD 234L) INPUT
NOISE:

Z_2 = INPUT IMPEDANCE

$G(\omega)$ = OP AMP TRANSFER FUNCTION

V_{IN} = VOLTAGE INPUT NOISE

$$-\left\{ \frac{(V_N - V_O)}{Z_1} + \frac{(V_O - V_O)}{Z_3} \right\} Z_2 G(\omega) = V_O$$

$$\left\{ -\frac{V_N + V_O}{Z_1} + \frac{V_O}{Z_3} \right\} Z_2 G(\omega) = V_O \left(1 + \frac{Z_2 G(\omega)}{Z_3} \right)$$

$$-\frac{V_N Z_2 G(\omega)}{Z_1} + \left(\frac{Z_2}{Z_1} + \frac{Z_2}{Z_3} \right) V_O = V_O \left(1 + \frac{Z_2 G(\omega)}{Z_3} \right)$$

$$\frac{Z_2 G(\omega)}{Z_1}$$

$$= \frac{V_O}{V_N} \left(1 + \frac{Z_2}{Z_3} + \frac{Z_2}{Z_1} + \frac{Z_2 G(\omega)}{Z_3} \right)$$

$$\frac{G(\omega)}{\left\{ \frac{Z_1}{Z_2} + \frac{Z_1}{Z_3} + 1 + \frac{Z_1}{Z_2} G(\omega) \right\}}$$

$$= \frac{V_O}{V_N} = \frac{G(\omega)}{-R_1/R_2 + R_1 C s + 1 - R_1 C s G(\omega)}$$

ASSUME: $Z_1 = R_1$

$Z_2 = R_2$ (INPUT IMPEDANCE REAL)

$$Z_3 = \frac{1}{C s}$$

$$Z_{OUT} = \phi$$

$$G(\omega) = \frac{K}{(1 + s/s_1)}$$

$$\frac{V_o}{V_s} = \frac{K}{-(1+s/s_1) \left(\frac{R_1}{R_2} + 1 \right) + R_1 C s (1+s/s_1) - R_1 C K}$$

$$= \frac{K}{-\frac{R_1}{R_2} + 1 + s \left(-\frac{R_1}{R_2} s_1 + \frac{1}{s_1} + R_1 C [1+K] \right) + R_1 C s^2 / s_1}$$

ASSUMPTION: $R_1 = 2K$ $\rightarrow$ $G_{INT} = \frac{200}{s}$ ← Coils with 10V2 $R = 2.2K$
 $C = 1E-06$
 $R_2 = 300K$
 $K = 10^7$ $\rightarrow$ SPIG
 $s_1 = 5E-03$

$$= \frac{10^7}{+0.99 + s(19.8K) + 8.45s^2}$$

$$= \frac{2.5E+07}{s^2 + 19.8Ks + 8.45}$$

$$= \frac{2.5E+07}{(s + 49.5K)(s - 5E-05)}$$

$$s = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$= \frac{49.5K \pm \sqrt{(6+1E-04)}}{-2}$$

$$= -49.5K, -5E-05$$

$$= 10.1E06 / ((1 + s/49.5K)(1 - s/5E-05))$$

BETWEEN $5E-05$ & $5E04$ ~~RAD/S~~
 THE 234L $\{R_{in} = 2K\}$ ACTS AS AN
 IDEAL INTEGRATOR:

$$V_o = \frac{1}{RC} \int V_{in} dt$$

THE INPUT NOISE {VOLTAGE} FOR THE
 234L OP AMP IS SPEC'D AT $0.7 \mu V_{pp}/\sqrt{Hz}$
 0.01 TO 1 Hz, and $1.5 \mu V_{pp}/\sqrt{Hz}$ 0.1 TO 10 Hz.

THE OUTPUT NOISE IS THEN APPROXIMATELY

$$\frac{1}{RL} \int 0.35 \times 10^{-6} \sin \omega t \quad \text{FOR } 0.01 < f < 1 \text{ Hz.}$$

SINCE MEASUREMENTS WILL TAKE ≈ 20 SEC,
AND THE COMPUTER CORRECTS FOR LINEAR
AND QUADRATIC DRIFT, $\omega = 2\pi/20$ WILL
BE THE MOST TROUBLESOME:

$$V_{0, \text{NOISE}} \approx \frac{1}{RL} 0.35 \times 10^{-6} \int_0^{20} \sin 0.314 t \, t$$

$$\text{or a drift of about } \left(\frac{1}{RL} \right) \frac{0.35 \times 10^{-6}}{0.314} = \frac{1}{RL} 1.1 \mu\text{V}$$

IS THEORETICALLY EXPECTED.

WE MEASURED THE OUTPUT VOLTAGE
DRIFT OF THE MTF INTEGRATORS
OVER A PERIOD OF 60 SECONDS,
SIMULATING 3 PASSES OF THE
SEARCH COIL THROUGH THE MAGNET.
AFTER THE COMPUTER CORRECTED FOR
LINEAR AND QUADRATIC DRIFT, THE
TOTAL DRIFT WAS $\approx 0.43 \mu\text{V}$.