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Some issues concerning beam sensing pick-ups

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AD

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SOME ISSUES CONCERNING BEAM SENSING PICK-UPS

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June 24, 1987

GENERAL

Pick-up electrodes are important in the Booster from the standpoint of machine control, observation of beam parameters such as beam shape, length, trajectory, orbit, etc., and for observation of spectra and motion in both transverse and longitudinal space.

Ideally, a pick-up having only a single design could do all of the needed sensing of beam parameters but for a complex machine such as the Booster, it may be necessary to have more than one design to allow observation and control of the parameter set which ranges over very wide ranges in frequency, intensity, and other dynamical beam properties.

In many machines two or more kinds of sensors have been used to secure data and other special features depending on the operational circumstances.

BOOSTER PICK-UPS

A favorite type of pick-up, for high frequency near relativistic bunched beams, the stripline, has been used to advantage to define the tem-

A favorite type of pick-up, for high frequency near relativistic bunched beams, the stripline, has been used to advantage to define the temporal, frequency domain, and position properties of beams in many synchrotrons. However, in the case of the Booster, where one must explore beam phenomena in the frequency spectral range in the few 100s of kilohertz to say several MHz, the properties of the stripline, particularly its large size which approaches $\lambda/4$ in length for high longitudinal impedance, are not good. The sensitivity of the pick-up, determined mainly by the effective longitudinal impedance, Z/n, diminishes rapidly below the most sensitive point defined by $Z/n = gR_0/\sqrt{2}$; $f_{max} = \frac{V_e}{4\ell}$, where R_0 is strip impedance, g = geometric factor, ℓ = length of electrode, and v_e = effective velocity.

The electrostatic pick-up consisting of plate electrodes in single units or arrays or the magnetic pick-up consisting of single or arrayed current transformer sensors will offer characteristics better matching beam temporal and frequency requirements. Note, however, that these devices need very careful attention to electrical and mechanical design factors if they are to be successful in accurately measuring the beam parameters and sensitive enough to be broadly useful. Generally, both pick-up types are characterized by a low frequency response region, i.e., a $G(s)= G(j\omega)=K_1(s)$ response, a flat mid-frequency region i.e. $G(s) = K_2$, and a high frequency region characterized by $G(s) = \frac{K_3}{(s)}$. For the elctrostatic device, the low low frequency response points ends at about $f = 1/\omega RC$ where R is the electrodes effective load resistance and C is the electrode capacity. The flat region extends to the point where the induced signal and the electrode structure exhibits resonant effects or where the electrode capacitance begins to dominate the impedance parameter and the pick-up integrates the beams induced signal. See Figure 1. Resonant effects are perhaps the most serious error producing effect in the electrostatic designs since both longitudinal and circumferential resonances can be generated, with some resonant effects developing in the mid-frequency region where the sensor is "supposed" to have constant (good) characteristics. Attachment points on the electrode plate play an important part in reducing the possible resonant modes of the electrode and its connecting strucutre/mechanism as do damping networks placed between adjacent electrodes for those pick-ups (multi-electrode) designed for position monitoring.

The magnetic pick-up has similar concerns and its response region are similar except that the low-frequency region ends at about $f = 1/\omega\ (L/R)$, where L is the equivalent sensor inductance and R is the load resistance. At first glance one would expect that the spurious resonance effects for this pick-up would be less than that of the capacitive electrode but if the magnetic loop is made large enough to obtain high transfer impedance as would be needed for obtaining reasonable voltages from low intensity beams, the loop area must be large and the physical structure of the loop must be correspondingly large, hence, the possibility of in-band spurious resonances exist because of stray capacitance. This effect seriously limits accuracy.

Note that generally, for all types of pick-ups, that the spectral portion of the beam induced signal which falls in the low-frequency region will be differentiated while that falling in the high frequency region will be integrated while good representation of the beams temporal characteristics will only be obtained if the beam spectrum falls within the flat part of the sensors response.

An additional factor that must be considered in the selection of the pick-up is how to transfer the developed sensor power (voltage) to the location where the signals are processed. Both the transfer impedance, $Zp = \frac{Vout}{Ibeam}$, and the frequency response associated with the device may be altered significantly and spurious noise effects may be serious due to ground currents. For example, for the case where the load resistor is extremely large, ($|j\omega CR| \gg 1$), $Z_p = g\ell/vC$, a relatively large value even for ℓ, and C small; for example a small capacitive pick-up may have a capacity of say 50 pf (25 pf plate + 25 pf stray), g = .5, a length of 0.1 meter and for $v = \beta c = 1.68E8$, (Booster inj,p^+), $Z_p = 5.95$ ohms. As a result, this pick-up (depending on the load resistor) is a very sensitive device compared to most striplines and single-loop magnetic devices. Note, however, that the high coupling impedance (Z/n) may impact the Booster machine design budget for the total allowable longitudinal impedance for the machine. If N such pick-ups (est 24 for Booster) are used for the position monitors, then the total longitudinal budget just for these devices is Z_pN = 143 ohms; a very large value for a high current machine.

If the pick-up electrode is loaded with a smaller load resistor, Z_p will be reduced but the device becomes reactive and mildly frequency sensitive (See Fig. 1). For example, for R = 100 ohms, C total = 50 pf, $\ell = .1$ meter, $\beta_{inj} = .56$, $Z_p \approx .41 \underline{/86°}$ ohms, at $f = f_{inj} = 2.5$ MHz. At extraction (4.1 MHz - P) the magnitude of Z_p is .46 ohms while the phase angle is lower, 83°.

The net result of terminating the pick-up electrode with the smaller resistor is to reduce Z_p by at least an order-of-magnitude (in this example) but the response of the device to the beam spectrum is now that of of a differentiator i.e., $V_{out} \propto \frac{d}{dt}(I_B(t))$ since the low frequency range is set to about, $1/2\pi RC \approx 32$MHz for the example parameters.

Z/n ISSUE

One of the important issues in the design of the Booster is whether the beam position monitor system can be designed to be compatible with the allowable longitudinal impedance budget for both high intensity proton operation and low intensity heavy-ion operation.

Clearly, if an impedance "modulator" attached to the electrodes and controlled automatically by ion or intensity logic, both objectives could be realized with the same sensor assuming the signal processing equipment could be contrived to handle the complex signals. (Figure 2). Also, there may be a plate terminating method using a single load resistor which could satisfy both high and low beam currents. A search for this alternative needs to begin.

The differentiated beam signals, inherent with small size low impedance pick-up structures, could easily be utilized in the high intensity mode (protons) to obtain position data with little machine performance impact because of the longitudinal impedance issues, but the beams temporal characteristics and measure of intensity would be difficult and prone to error if these parameters were to be determined from the same sensor. On the other hand, for the low intensity heavy ion beams the electrodes could be terminated in a high impedance permitting the needed broad frequency response together with better coupling to the beam for improved signal-to-noise ratio and there would be little impact on beam stability or longitudinal impedance issues.

An alternative plan would be to include 4 small ($g \approx \frac{1}{20}$) "button" pick-ups in an integral arrangement with the plate assemblies. In such an arrangement the plate electrodes would be provided with a switched low impedance load such that for the operation with high β and high intensity protons the plates would be grounded, making the coupling impedance nearly zero. The button pick-ups would then be used in the normal way for position information for protons and because of $g = \frac{1}{20}$, the Z/n would be small in this mode. The advantage of the technique is that the shorting switch contacts used to control the Z/n of the plates would not have to be precisely established at a specific value (a few milliohms-to-a few ohms would be okay).

In the design of the signal transmission cabling, from beam line to electronics processor a great deal of care must be exercised with either concept so as to eliminate the inherent "noise" spectrum from dc-to-a few tens of kilohertz so as to avoid mixing the spurious noise content with the beam developed signals. At least two techniques are applicable here (1) insulate the pick-up assembly from the beamline and (2) increasing the transfer cable impedance by use of a set of cable/ferrite core impedance transformers. Both techniques (Fig. 3) add cost and complexity to the system but will pay, handsomely, in good signal reproduction at the signal processing terminal point.

APPENDIX

Appendix I contains some general information about beam pick-ups and beam signal processors.

SUMMARY

1. For the Booster capacitive plate pick-ups appear to be the best choice. Careful mechanical arrangement of the assembly together with care in electrical cable attachment methods will be mandatory for stable operation.
2. Z/n consideration dictate some technique either to modulate the longitudinal impedance when the machine is operated in its various modes, heavy ions, or high intensity proton production or a compromise plate termination scheme developed to satisfy both high and low beam currents.
3. Much care is needed in the design of the pick-up electrodes and its mechanical design to eliminate resonance effects.
4. The signal transport from pick-up to the electronic processor must be designed to reduce/eliminate the spurious ground currents which could produce serious error if mixed with the beam developed signals within the spectra area of interest.

Ref Cy

I

BEAM DETECTORS AND SIGNAL PROCESSORS

DISCUSSION OUTLINE

I OVERVIEW

II THE BPM SYSTEM PROBLEM

III SENSORS & PROCESSORS

IV DOs, DON'Ts, SUMMARY

LOS ALAMOS NATIONAL LABORATORY
E. F. HIGGINS AT-5
Nov. 1, 1986

PART I - OVERVIEW

*SOME GENERAL ATTRIBUTES OF BEAM LINE INSTRUMENTATION

- o DETECT
- o LOCATE
- o QUANTIFY
- o MONITOR
- o CONTROL

*ITEMS OF SPECIAL INTEREST TO ACCELERATOR SCIENCE

- o INTENSITY –
  - * AVG. BEAM CURRENT
  - * NUMBER DENSITY OF CHARGES
  - * ABSOLUTE, RELATIVE
- o POSITION –
  - * 1ST MOMENT CENTROID
  - * LOCATE RELATIVE TO REFERENCE
  - * TRAJECTORY/ORBIT
- o ENERGY –
  - * KINETIC, MASS VELOCITY RELATION
- o PROFILES –
  - * TRANSVERSE CHARGE DISTRIBUTION
  - * LONGITUDINAL CHARGE DISTRIBUTION
- o SPECTRA –
  - * BEAM CONTENT
  - * BETATRON MOTION
  - * SIDEBAND STRUCTURE

- o KINETIC RELATIONS -
  - * TUNES
  - * COHERENT MOTION
  - * BEAM BREAKUP
  - * DAMPING
  - * MOMENTUM SPREAD
  - * BEAM TRAVEL TIME
- o EMITTANCE -
  - * CROSS SECTION x EMISSION SOLID ANGLE
- o RADIATIONS -
  - * SYNCHROTRON
  - * NUCLEAR
  - * STRAY RF FIELDS
  - * X-RAY, RF
- o OTHERS -
  - * MANY

GOOD INSTRUMENTATION HELPS

- o UNDERSTAND MACHINE DYNAMICS
- o VERY USEFUL IN COMMISSIONING
- o IMPORTANT IN GENERAL MAINTENANCE
- o MAKES POSSIBLE OPERATIONAL PROCEDURES
- o PROVIDES HISTORY OF MACHINE SETTINGS & ADJUSTMENTS FOR ANALYSIS
- o BASIS FOR MANY UPGRADE SPECIFICATIONS
- o SAFETY

WHAT'S IMPORTANT ABOUT BEAM POSITION MONITORS

- o ESTABLISH ORBIT OR BEAM PATHWAY / TRAJECTORY
- o PRIMARY TOOL FOR TRANSVERSE MOTION ANALYSIS, SPECTRUM
- o AIDS IN ACQUISITION STEERING PARAMETERS FOR BENDS, BUMPS, ETC.
- o HELPS, FIND, AND CONTROL INSTABILITIES
- o SETS ORBIT RADIUS (SYNCHROTRONS) COUPLED TO RF
- o CAN BE COUPLED WITH INTENSITY TO OBTAIN SPECTRAL ANALYSIS AND LOSS DATA
- o HELPS IN MONITORING CRITICAL OFFSETS, AIDS IN ADJUSTMENT OF KICK, BEND, BUMP FIELDS.

BPM GENERAL FACTORS

- o NEEDS SENSOR TO INTERROGATE & MEASURE BEAM FIELDS

- o MACHINE DESIGN DICTATES ARCHITECTURE
  - * BEAM PARAMETERS
  - * BEAMLINE CONFIGURATION
  - * TYPE OF ION
  - * CHARGED, UNCHARGED, PARTICLE
  - * DESIRED TYPE OF SERVICE
    - (A) MONITOR
    - (B) CONTROL
    - (C) STUDY

- o SPEED OF RESPONSE, LOCATION, ACCURACY, RESOLUTION, DYNAMIC RANGE, DICTATE TYPE OF CIRCUITS

- o DATA USE DICTATES HOW SYSTEM INTERFACED WITH I & C.

PART II - THE SYSTEM PROBLEM

- o DETERMINE CENTROID RELATIVE TO REFERENCE (WITH REQUIRED ACCURACY AND PRECISION)

  * MEASURE WITHOUT BEAM INTERCEPTION
  * RESULT INSENSITIVE TO INTENSITY, OR BUNCH WIDTH
  * RESULT MONOTONIC WITH DISPLACEMENT
  * RESULT WITHOUT HYSTERESIS, DEAD-BAND, SPURIOUS NOISE
  * NEGLIGIBLE EFFECT ON BEAM OR BEAM GUIDEWAY
  * COST EFFECTIVE-MANY MONITOR LOCATIONS
  * EASY TO OPERATE AND COMPATIBLE WITH I & C

SOME SYSTEM FACTORS

- SENSORS SHOULD PROVIDE CAPABILITY TO PROCESS BEAM FOR ODDNESS ABOUT BEAM LINE ℄ IE., F(x) = - F (-x) → IMPLIES SEVERAL SENSORS IN CLUSTER.

- ATTACHMENT CABLES SHOULD NOT DEGRADE SENSOR QUANTITIES SIGNIFICANTLY - LOW LOSS/DISPERSION

- PROCESSORS MUST MEET ACCURACY & PRECISION WITHOUT DRIFT OR NOISE ERROR - PASSIVE PROCESSING IF POSSIBLE

- INTERFACES MUST CONVEY PROCESSED DATA TO I & C WITH APPROPRIATE SPEED AND RESOLUTION - SPECIAL CODE FORMAT & ISOLATED INTERCONNECT BUS IF POSSIBLE

- COMPONENT DAMAGE - BEAMLINE COMPONENTS MUST OPERATE IN SEVERE ENVIRONMENT - DECOUPLE FROM BEAM RADIATIVE EFFECTS & USE RAD HARD MATERIALS

GENERAL SYSTEM ACCURACY/RESOLUTION

- ACCURACY & RESOLUTION CONDITIONAL WITH

  * MECHANICAL ALIGNMENT ERROR
  * ELECTRONIC PROCESSING ERROR

    (A) DRIFTS
    (B) NONLINEAR EFFECTS
    (C) OFFSETS
    (D) DELAY - RESPONSE TIME
    (E) SPURIOUS NOISE AND INTERNAL EQUIPMENT NOISE

  * NOISE ERROR DUE TO SIGNAL-TO-NOISE(SNR) EFFECTS THERMAL NOISE

- BEST ACCURACY FOR SNR @ 60 dB ABOUT 0.5 % APERTURE

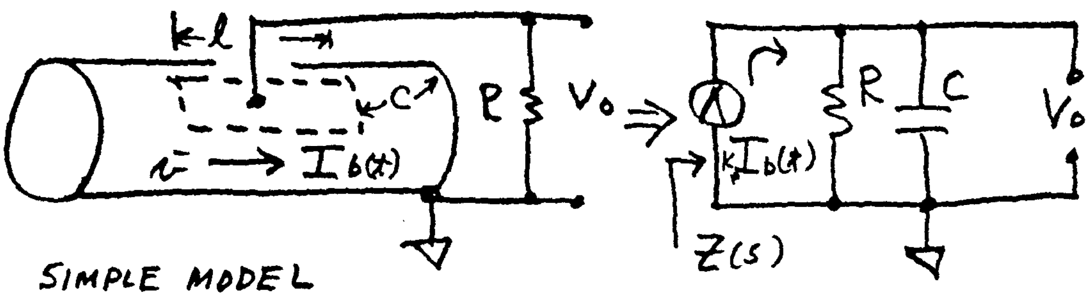
- BEST RESOLUTION FOR SNR @ 60 dB ABOUT 0.05%

- SNR DEPENDENCE $\sigma x \rightarrow \left(\frac{1}{\Delta SNR}\right)^{\frac{1}{2}}$

PART III SENSORS & PROCESSORS

- o <u>SENSOR OVERVIEW</u>
  - * CAPACITOR ELECTRODE
  - * MAGNETIC LOOP
  - * STRIPLINE
  - * WAVEGUIDE
  - * CAVITY WITH PROBE/LOOP
  - * SLOT & TEM STRIP
  - * OTHER

CAPACITIVE BEAM SENSOR



SIMPLE MODEL

$$\Delta t = \frac{l}{v_{beam}} = \frac{l}{\beta c}$$

K_p = CONSTANT FOR PIPE GEOMETRY – coupling factor relatel to size of Electrode. $s = j\omega$

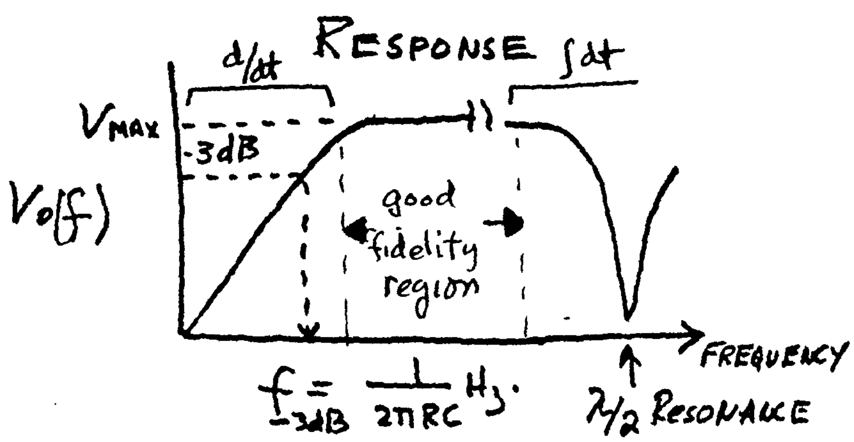
$$Z(s) = R/1+RCs$$

$$V_o(s) = \left[K_p \frac{l}{\beta c}\right] I_b(s)\,(s)\left(\frac{R}{1+RCs}\right)$$

(s = $j\omega$)

$$V_o(t) = \left[K_p \frac{l}{\beta c}\right] \mathcal{L}^{-1}\left\{ I_b(s)(s)\left(\frac{R}{1+RCs}\right)\right\}$$

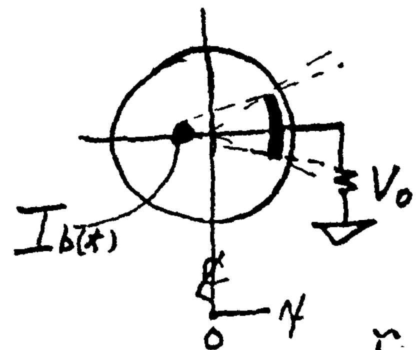
THESE ARE HI-PASS RESPONSES

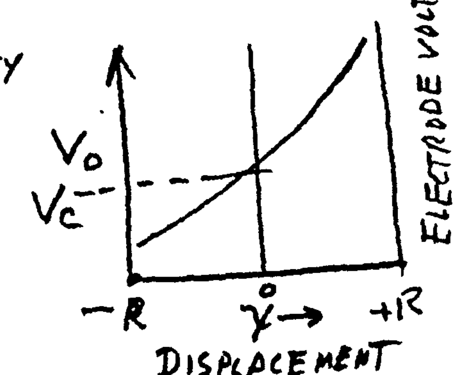


$f_{-3dB} = \frac{1}{2\pi RC}$ Hz.

λ/2 RESONANCE

$f_r = \left(\frac{2c}{l}\right)$ Hz.





$$Z_p = \frac{j g \omega l}{\beta c} \cdot \frac{R}{1 + j\omega RC}$$ = Longitudinal Coupling Impedance.

See LBL Report 22085, p.14

FOR DIFFERENT FORMULATION SEE:

LANL, PSR DESIGN NOTE #4, 4/14/78

ALSO LANL, PSR DESIGN NOTE #27, 7/16/79

RESULT IS:

$$V(t) = \frac{\epsilon_0 A}{C}\left\{ E_r(t) - \frac{1}{\tau} e^{-t/\tau} \int_{-\infty}^{t} E_r(t') e^{\frac{t}{\tau'}} dt' \right\}$$

where $$E_r(r_p,t) = \frac{\gamma}{2\pi\epsilon_0 r_p} \sum_0^{\infty} 2 l_m \cos\left(\frac{2\pi m V t}{L}\right) \Big/ I_0\left(\frac{2\pi m r_p}{\gamma L}\right)$$

$$\gamma = \left[1 - \frac{v^2}{c^2}\right]^{-1/2}$$

E_r = Radial Electric Field

ϵ_0 = Permitivity

C = Plate Capacity

A = Plate Area

τ = Time Constant Z_0/C

t, t' = time

l_m = Charge coefficient

PLATE PICK-UP CONCERNS

- o POOR DRIVER → Z DRIVE REACTIVE
- o SPURIOUS RESONANCES → RIPPLE IN TIME DOMAIN
- o STRAY C^S A PROBLEM IN SUPPORT & COUPLING STRUCTURES → $C_{STRAY} \approx C_P$
- o MATCHING 2 OR MORE DEVICES DIFFICULT → SPURIOUS VARIATIONS
- o INTERCOUPLING BETWEEN PLANES DIFFICULT TO REMOVE → 20 dB
- o LOW FREQ PERFORMANCE POOR → (S) IN NUMERATOR, (R) LOAD SMALL
- o DIRECTIVITY → NONE

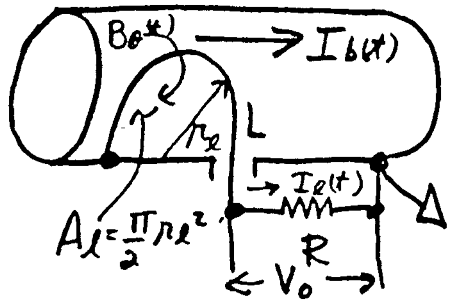
OK FEATURES

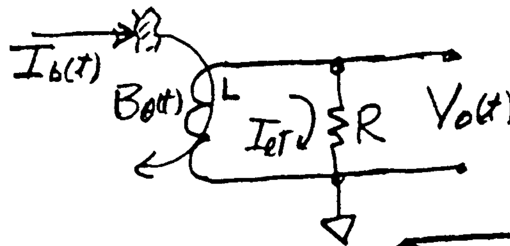
- * TRANSFER Z HIGH → $>5\ \Omega$ *
- * BUTTON TYPE EASY TO IMPLEMENT
- * SMALL SIZE FOR SOME TYPES
- * LOW BANDWIDTH → CAN USE A $(o-jx) \to (R+jo)$ CONVERTER

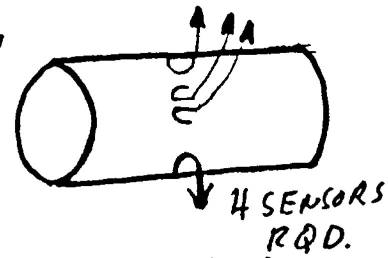
↓ Because of Spurious resonances.

*

MAGNETIC LOOP BEAM SENSOR







$$V_0(t) = V_1 + V_2 = i_\ell(t) R$$

where V_1 = INDUCED BY BEAM COUPLING FIELD VIA $B_\theta(t)$ & $\dot{\phi}$

V_2 = SELF INDUCTION IN LOOP BY $I_\ell(t)$

$$V_1 = -N \frac{d}{dt}(\phi_\phi(t))$$

$$V_2 = -L \frac{d}{dt}(i_\ell(t))$$

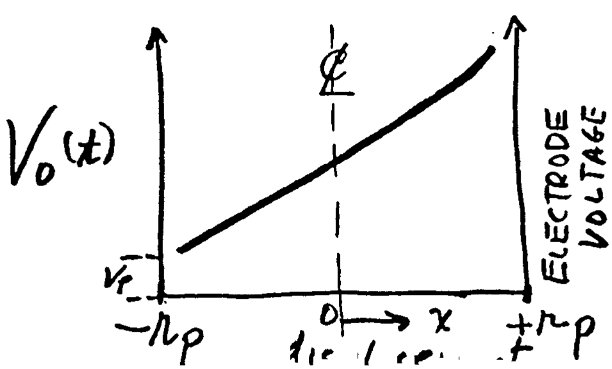
$$B_\theta(t) A = \frac{\mu_0}{2\pi r_p} \frac{d}{dt}\left[I_b(t)\right] \times \frac{\pi r_\ell^2}{2}$$

$$V_0(t)\Big]_{N=1} = i_\ell(t) R = \frac{-\mu_0 r_\ell^2}{4 r_p} \frac{d}{dt}\left[I_b(t)\right] - L \frac{d}{dt}(i_\ell(t))$$

HIGH PASS FUNCTION

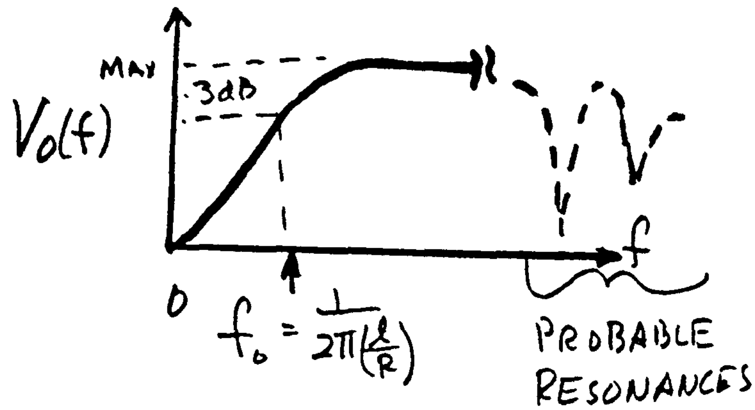
$$V_0(s) = \frac{-\mu_0 r_\ell^2}{4 r_p} I_b(s)(s)\left(\frac{1}{1+\left(\frac{L}{R}\right)s}\right) = \mathcal{L}\{V_0(t)\}$$

$$V_0(t) = \mathcal{L}^{-1}\left\{-\frac{\mu_0 r_\ell^2}{4 r_p} I_b(s)(s)\left(\frac{1}{1+\frac{L}{R}s}\right)\right\}$$



● MAGNETIC LOOP SENSOR

* FREQUENCY CHARACTERISTIC

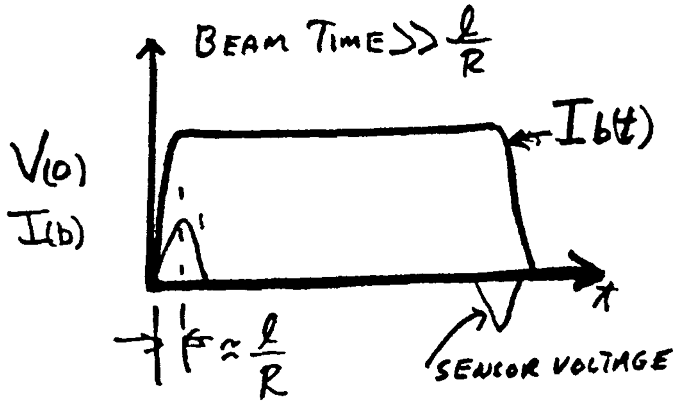


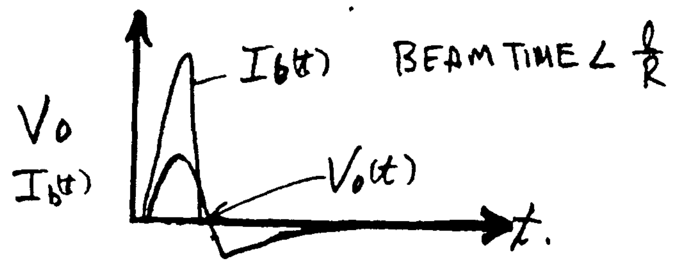
Note: $V_o(f) \propto K(s)$

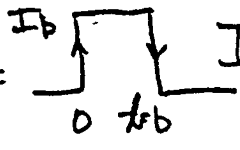
where $s \rightarrow \frac{d}{dt} f(t)$

∴ For $I_b(t)$ long compared to region sampled by loop, SENSOR differentiates

* Beam time $T_B = \frac{l_B}{v_B} \gg \frac{l}{R}$ $V_{OUT} \propto \frac{d}{dt}(I_B(t))$





* EXAMPLE: — $I_b(t) =$  $I(s) = I_b \times \left(\frac{1}{s}\right)\left(1 - e^{-t_b s}\right)$

then: $V(s) = -K I_b \,s \times \frac{1}{s} \times 1 - e^{-t_b s} = -K I_b \left\{ \frac{1 - e^{-t_b s}}{s + a} \right\}$

$$V(t) = -K I_b \left\{ e^{-t/L/R} - e^{-(t - t_b)/L/R} \right\} ; \text{ for } t_b \gg \frac{l}{R} \rightarrow \frac{d}{dt} K I_b(t)$$

* FOR MORE DETAIL SEE REFERENCES FOR CAP SENSOR

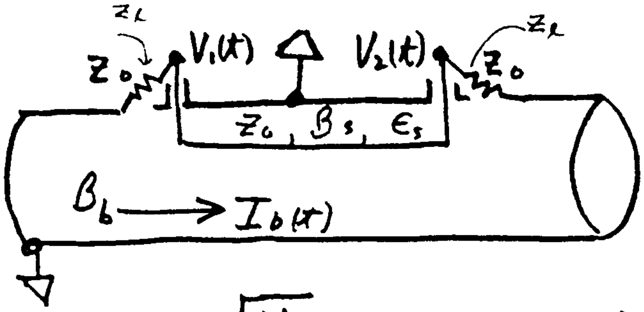
MAGNETIC LOOP PICK-UP CONCERNS

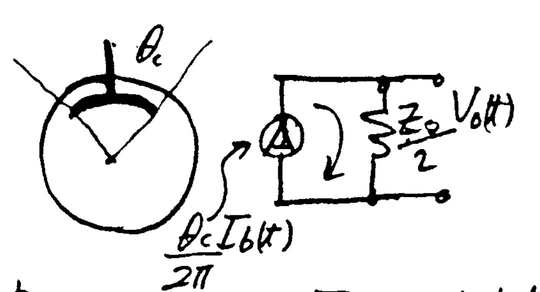
- o POOR DRIVER → Z DRIVE REACTIVE
- o SPURIOUS RESONANCES → WITH STRAY CS, RIPPLE
- o STRAY PARTICLES CAN INDUCE CHARGE → CAUSE ERROR
- o TRANSFER Z USUALLY VERY LOW→ Z_M < 1 OHM
- o USUALLY POOR LOW FREQUENCY PERFORMANCE

OK FEATURES

- o SMALL SIZE → LOW PROFILE
- o EASY TO SUPPORT
- o CAN BE SHIELDED →REDUCE STRAY PARTICLE EFFECTS
- o NARROW BAND → CAN USE (O-JX)→(R+JO) CONVERTER
- o GOOD FOR "IN-CAVITY" USE

• STRIPLINE BEAM SENSOR





$Z_0 = \sqrt{L/C}$, L, C, per unit $\frac{\Phi_0}{2\pi}$ = Fraction of $I_i(b)(t)$ collected

$\beta_s c = v_{STRIP} = c/\sqrt{\mu_r \epsilon_r}$ Real   GHOST

$$V_1(t) = \frac{Z_0}{\sqrt{2}}\left(\frac{\Phi_0}{2\pi}\right)\left\{I_b(t) - I_b\left(t - \frac{\ell}{\beta_b c} - \frac{\ell}{\beta_s c}\right)\right\}$$

$\sqrt{\frac{Z_0 Z_\ell}{2}}\left(\frac{\theta_c}{2\pi}\right) \rightarrow \frac{Z_0}{\sqrt{2}}$

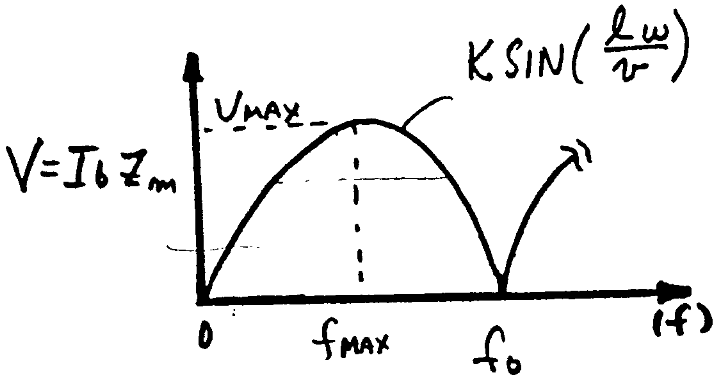
$$V_2(t) = \frac{Z_0}{\sqrt{2}}\left(\frac{\Phi_0}{2\pi}\right)\left\{I_b\left(t - \frac{\ell}{\beta_s c}\right) - I\left(t - \frac{\ell}{\beta_b c}\right)\right\}$$

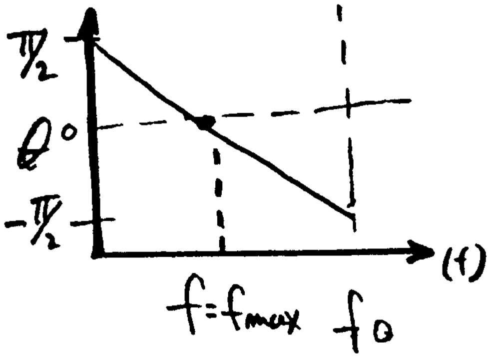
Note: if $\beta_s = \beta_b$, $V_2(t) = 0$ and no signal appears at the downstream port

Also: $t_{CLIP} = \left(\frac{\ell}{\beta_b c} + \frac{\ell}{\beta_s c}\right)$ = Time between Real and Ghost signals

• FREQUENCY DOMAIN CHARACTERISTIC

$\ell = \frac{.05 \times 3 \times 10^5}{f15 \times 10^3 \times 4}$ 21





$$f_0 = \frac{v}{2\ell}\ ,\quad f_{max} = \frac{v}{4\ell}\ ,\quad \theta = \frac{\pi}{2} - \left(\frac{\ell\omega}{2}\right)$$

o SYSTEM DEFINED

1. OVERALL SYSTEM GOAL STATEMENT

2. SENSORS

3. BEAMLINE ATTACHMENTS

   (A) FLANGES
   (B) CAVITIES
   (C) FEEDTHRUS
   (D) IMPEDANCE CONVERTERS

4. CABLE SYSTEM & MUX

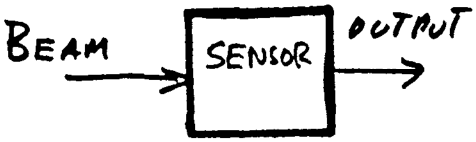
5. ISOLATION SCHEME

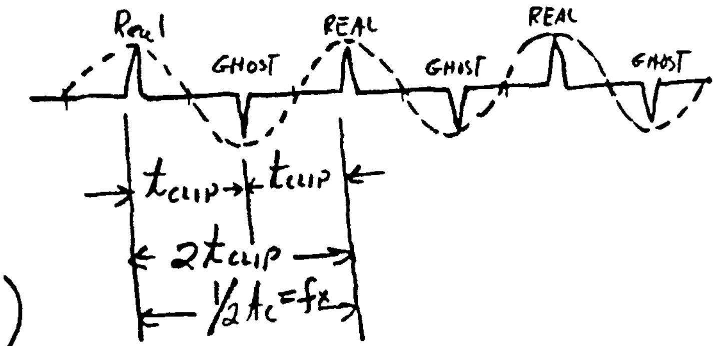
6. PROCESSOR ELECTRONICS

7. CONTROLS INTERFACE

8. DISPLAY & OPERATIONS

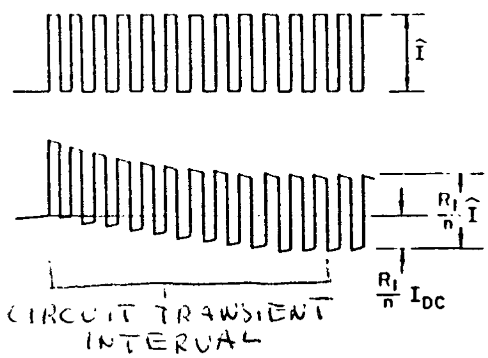
- **SIGNAL PROCESSING** — TO CREATE DOMINANT FREQUENCY $f_x = f_{BUNCH} = \frac{1}{t_{BUNCH}}$.





$$f_x = \frac{1}{2t_{CLIP}} = \frac{1}{2\left(\frac{l}{\beta_b c} + \frac{l}{\beta_s c}\right)}$$

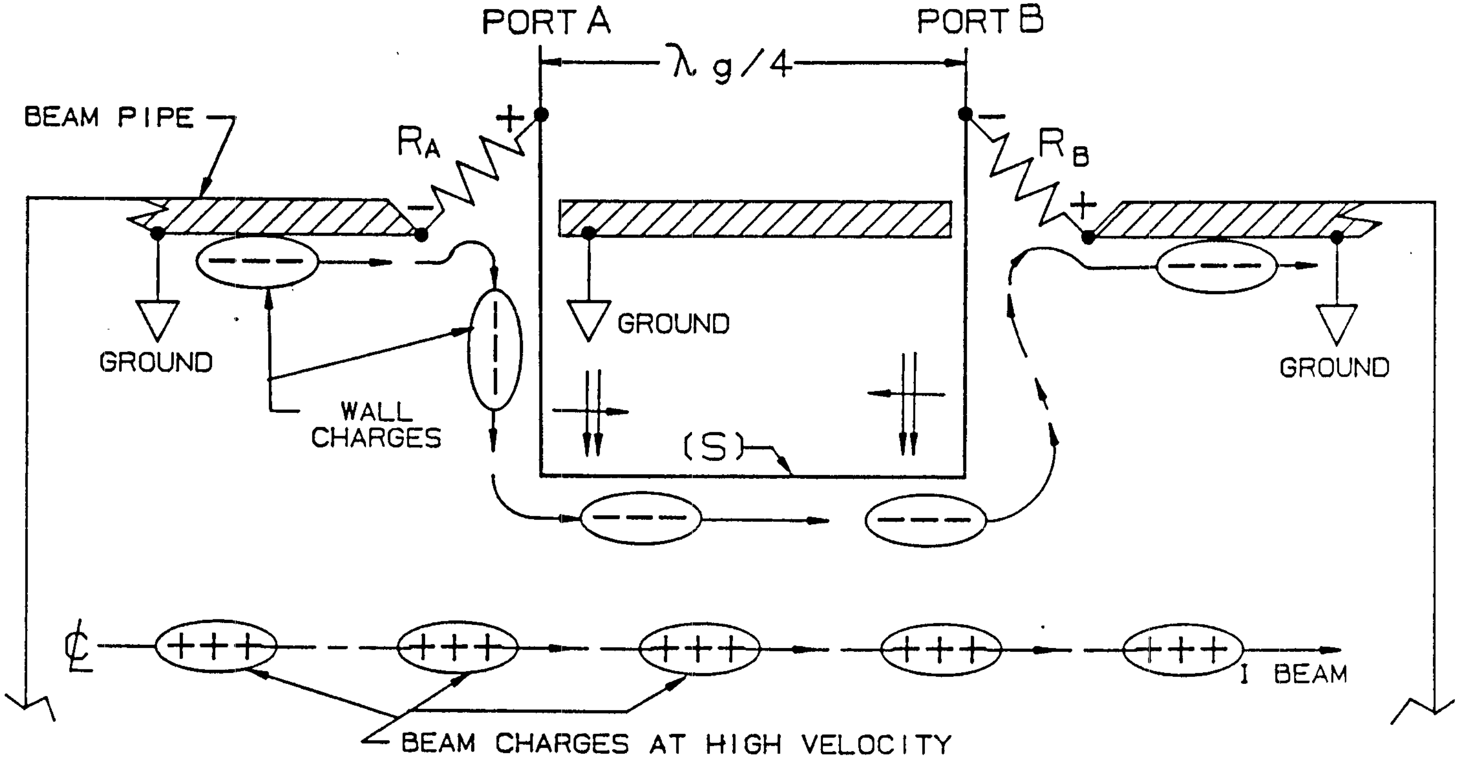
- Note: $f_x = \frac{1}{t_{BUNCH}}$; dc value $= 0$, $\therefore$ GOOD DRIVE TO FILTER i.e., NONE OF THIS EFFECT



- $$l_{(f_x)} = \frac{c}{2(f_x)\left(\frac{1}{\beta_b} + \frac{1}{\beta_s}\right)}, \text{meters}$$ = LENGTH OF PLATE TO FURNISH $f = f_x$

BEAM SENSOR DIAGRAM (SINGLE QUADRANT)

1/4 BEAM PIPE SHOWN



- WALL CHARGES FLOW THRU R_A & R_B ALONG STRIPLINE (S)
- PORT A & B VOLTAGES EXCITE STRIPLINE AT BOTH ENDS
- PORT A VOLTAGE PROPORTIONAL TO BEAM CHARGES & PORT B VOLTAGE=0

FIG.12

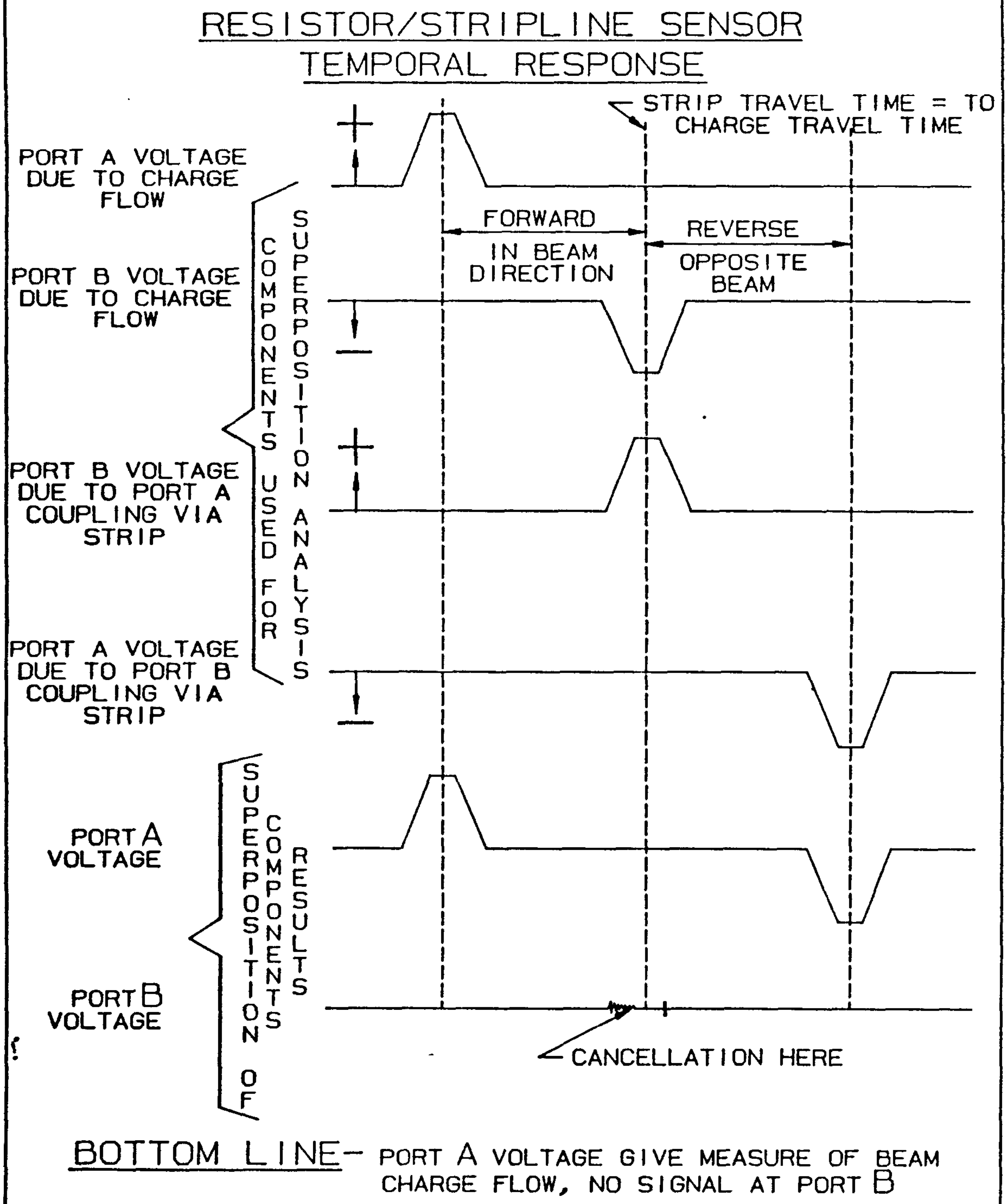

RESISTOR/STRIPLINE SENSOR
TEMPORAL RESPONSE
STRIP TRAVEL TIME = TO CHARGE TRAVEL TIME
PORT A VOLTAGE DUE TO CHARGE FLOW
FORWARD
IN BEAM DIRECTION
REVERSE
OPPOSITE BEAM
PORT B VOLTAGE DUE TO CHARGE FLOW
COMPONENTS USED FOR
SUPERPOSITION ANALYSIS
PORT B VOLTAGE DUE TO PORT A COUPLING VIA STRIP
PORT A VOLTAGE DUE TO PORT B COUPLING VIA STRIP
PORT A VOLTAGE
PORT B VOLTAGE
SUPERPOSITION OF
COMPONENTS
RESULTS
CANCELLATION HERE
BOTTOM LINE- PORT A VOLTAGE GIVE MEASURE OF BEAM CHARGE FLOW, NO SIGNAL AT PORT B

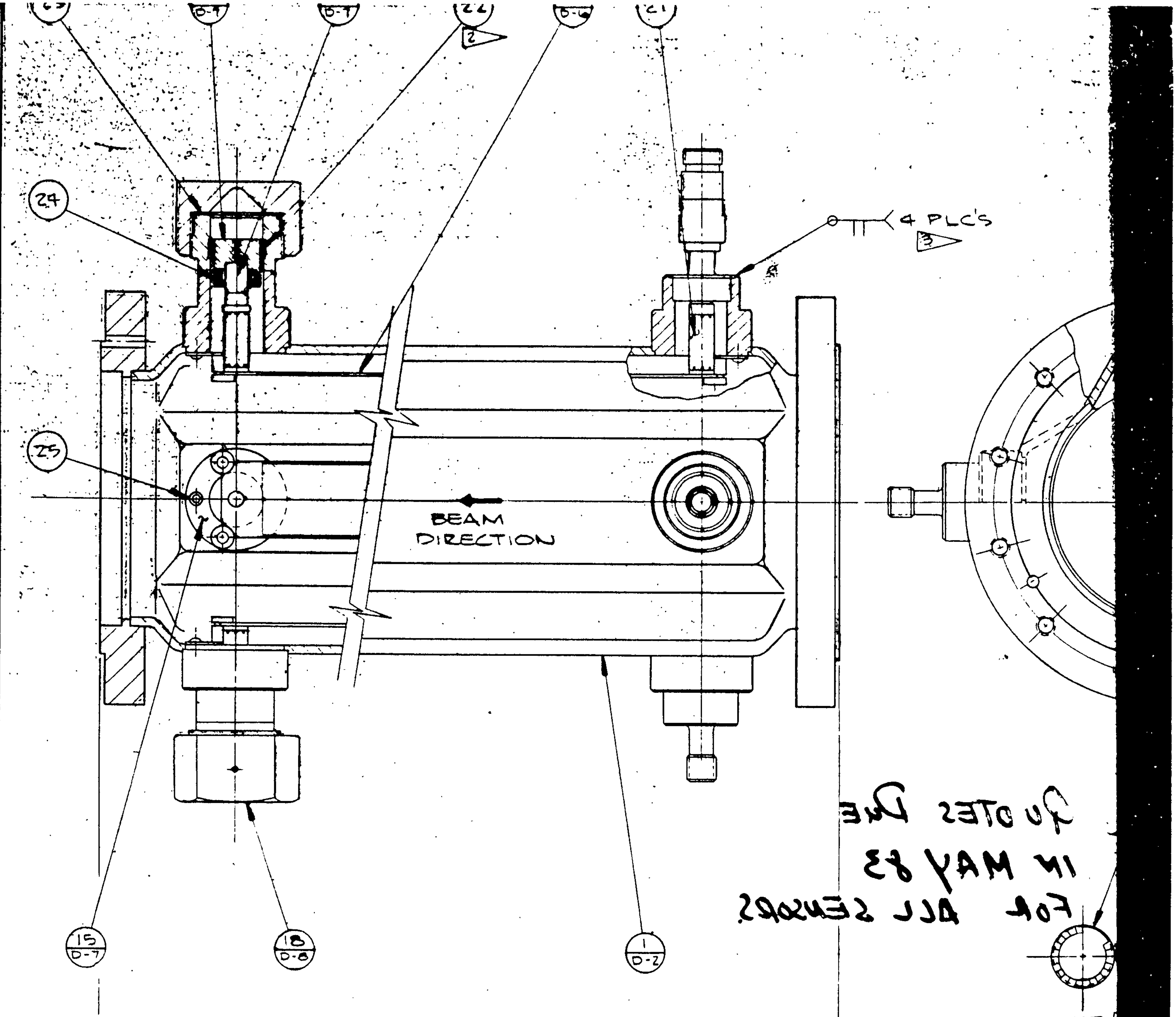
FIG. 14

STRIPLINE PICK-UP FACTORS

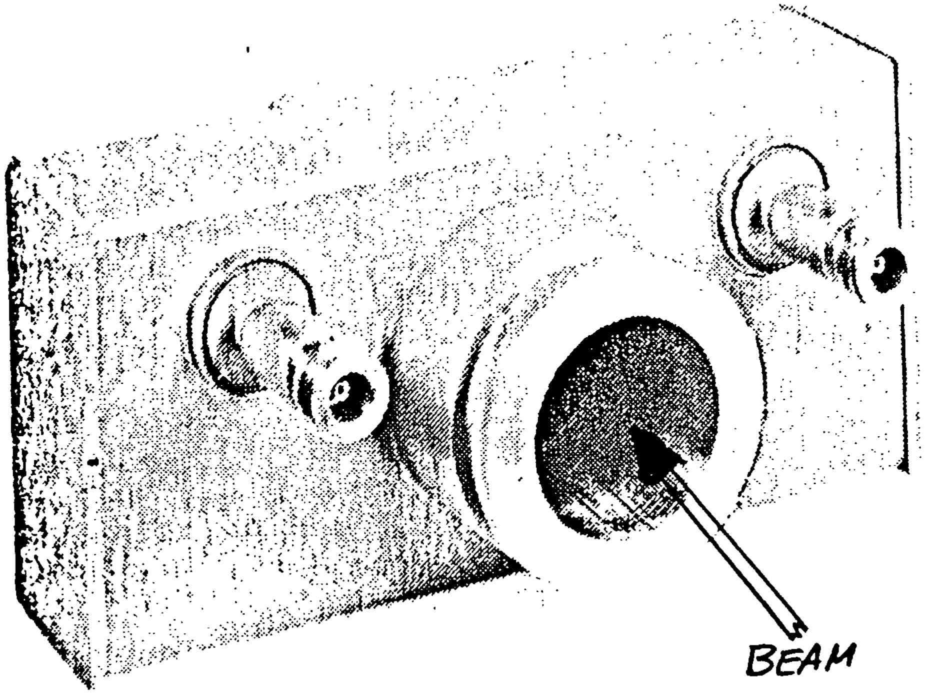
- o BROAD BAND → 1 - 2 OCTAVES, 2 DECADES SPECIAL
- o GOOD DRIVER → REAL, @ Z_0 STRIP
- o GOOD INTENSITY SENSITIVITY → 2 - 5 OHMS
- o FAITHFUL REPRODUCTION → UNTIL (t_{clip}) REAL TO GHOST TIME
- o EXCELLENT ISOLATION BETWEEN PLANES → >40 dB
- o LOW BEAM EFFECTS → Z/m «1-4 OHM
- o DIRECTIONAL IF REQUIRED → 20 - 26 dB
- o PRODUCES DOUBLET → CAN BE USEFUL

NOT SO GOOD

- o NEGATIVE GHOST → STARTS AT (t_{clip})
- o DIFFICULT TO CONSTRUCT → NEED GOOD TOLERANCES
- o ZEROS IN PASSBAND → IF NOT COMPENSATED


24
22
4 PLC'S
3
2
25
BEAM
DIRECTION
15
D-7
18
D-8
1
D-2
Quotes Due
in May 83
For all sensors

WAVEGUIDE BEAM SENSOR



- **S-band DEVICE @ 3 GHz**

$$P_{OUT_{pk}} = K\, I_{b_{pk}}^2\, \mu\,\text{watt}$$

$$K \approx 16\ \mu W/ma^2$$

For 1ma

$$P = 16\ \mu\text{Watt}$$

For $Z_0 = 50\,\Omega$

$$V_0(t) = 28\,mV\,pk$$

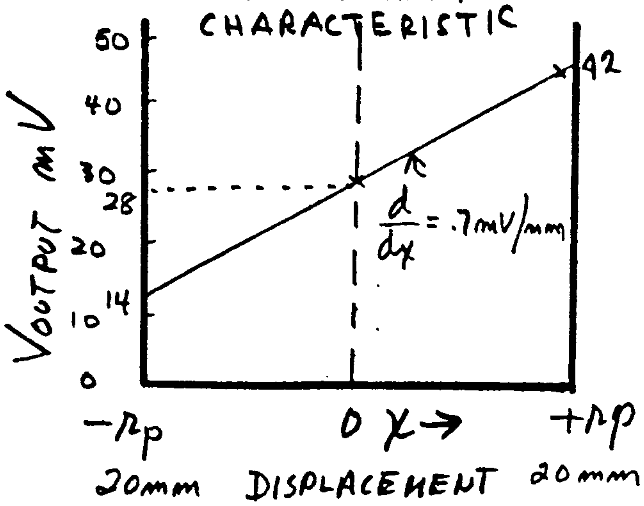
- **$\Delta\phi$ Phase Sensitivity $\frac{Deg.}{mm}$**

$$\Delta\phi = \frac{K \times 360}{\lambda_e} = \frac{1.4 \times 360 f}{c} = 5°/mm$$

- **DISPLACEMENT SENSITIVITY**

$$S_x = K\,\frac{mV}{mm}\,ma$$

$$K \approx 0.7\,mV/mm$$



WAVEGUIDE PICK-UP FACTORS

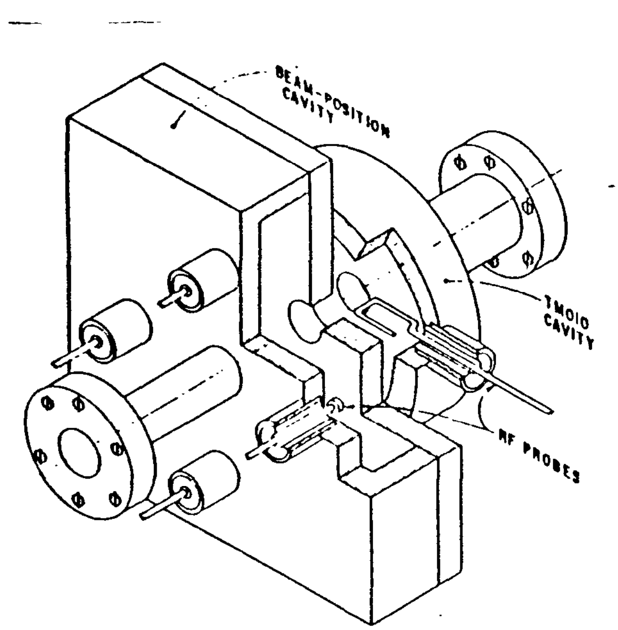
- o Good sensitivity → 0.7 mV/mm displacement
  → 5° /mm phase displacement
- o Small size → Beam spectral components needed at microwave frequency
- o Driver connection matched → special transition
- o Direct phase processing possible → good feature
- o Wide bandwidth → possible with ridged guide
- o Good Linearity → over 0.5 aperture

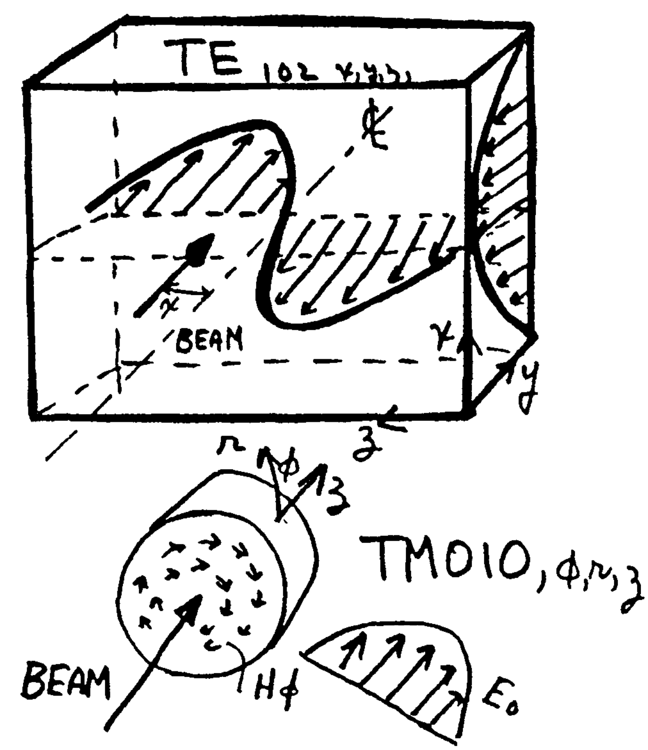
Concerns

* High Z_{IN}
* Need 2 structures for dual plane
* Spurious mode excitation

CAVITY PICK-UP

- Uses beam to excite modes for position, electric coupling
- Uses thin associated cavity and magnetic coupling for intensity
- For position → square cavity using TE 102, TE 201 mode
- For intensity → round cavity using TM_{010} mode
- Shunt z(position) → changes with displacement

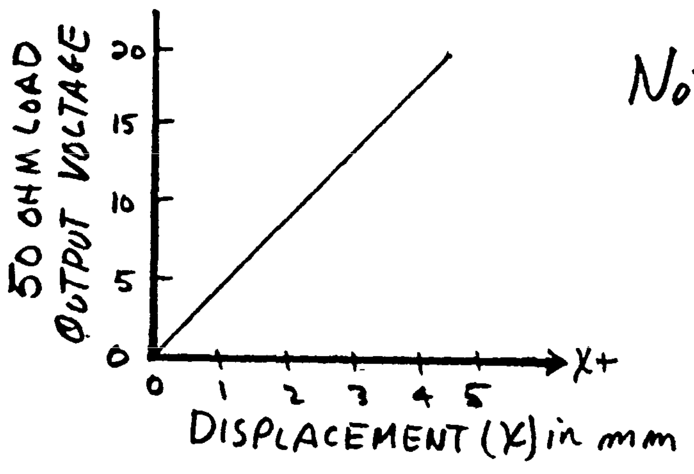




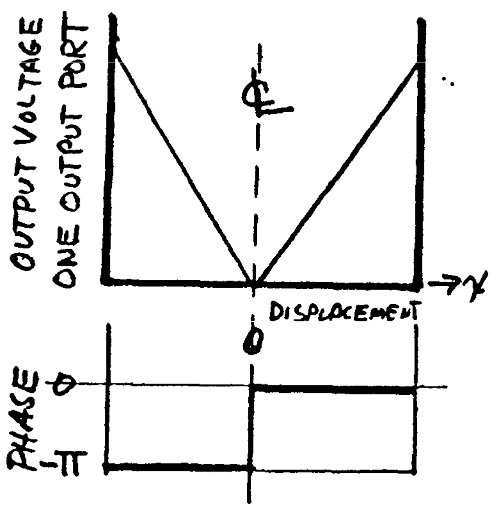
CAVITY BEAM SENSOR

- For Position Power Output = zero on axis
  ie., TE 102 mode not excited
- For off axis $P_{(x)} = (I_{b(t)} X)^2 Z_m$
  where $Z_m \approx 5$ ohms/mm² @ S-band.
- Typical Example @ S-band for 300 μA cw beam, 1mm
  $P_{(x)} = (300 \times 10^{-6} \times 1mm)^2 \times \frac{5\Omega}{mm} = \underline{450 \times 10^{-9}}$ Watts pk

Availible $V_{o(t)}\Big]_{50\Omega} = \frac{V^2}{Z_o} = \underline{4.7 mV_{pk}}$



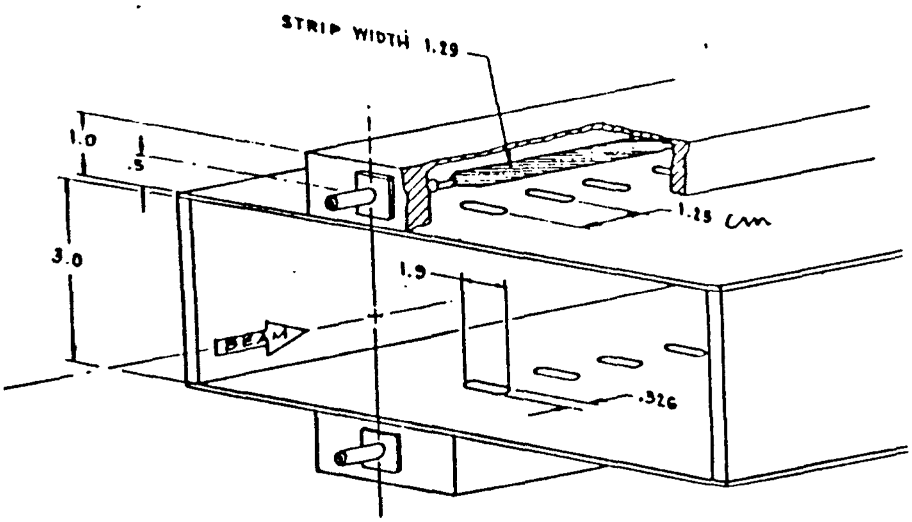
NOTE: Function passes thru ZERO



NOTE: PHASE CHANGES BY π WHEN BEAM MOVES ACROSS AXIS ∴ PROCESS BY SYNCHRONOUS DET.

<u>SLOT COUPLED BEAM SENSOR</u>

- o BEAM E-M FIELDS LEAK OUT SLOTS
- o SLOTS ENERGIZE TEM STRIP
- o APPLICABLE FOR SENSOR WHEN BEAM SPECTRUM IN MICROWAVE REGION



$$V_o = Z_m I_b(t)$$

$$Z_m \to 58 \sin(kNf)$$

$$V_o = 58 \sin(kNf) I_b(t)$$

Where K = Geometric Constant 9.24×10^{-3}

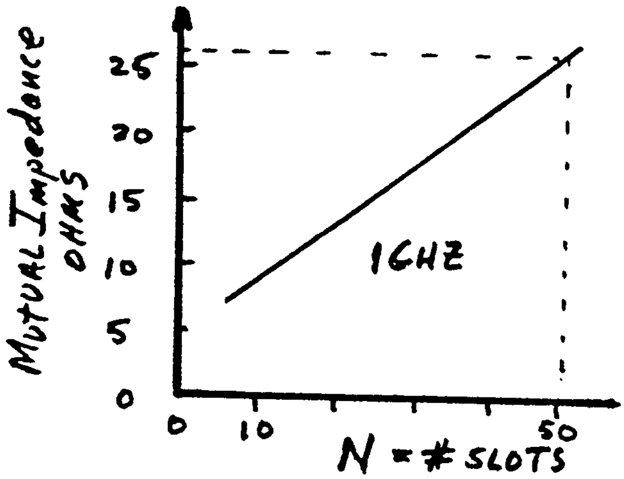
f = frequency in GHz

N = Number of slots in array

SLOT COUPLED TEM-LINE SENSOR

EXAMPLE: What is Z_m Versus N @ L-band. 1.0 GHz.

Slot spacing ≈ $\lambda/8$



MORE INFO-SEE: IEEE TRANSACTIONS ON NUCLEAR SCIENCE 4 AUG 1983 PAGE 2158

SLOT PICK-UP FACTORS

- o COMPACT SIZE → FEW λ_0 LONG AND RELATIVELY FLAT
- o BROAD BANDWIDTH → 1-2 OCTAVES
- o HIGH SENSITIVITY → Z_M, 5-20 OHMS
- o CONSTRUCTION SIMPLE

CONCERNS

- * SPURIOUS MODES IN TEM LINE
- * Z_M HIGH IF LONG
- * GOOD ONLY AT MICROWAVE FREQUENCY

SOME IMPORTANT PROPERTIES OF SENSORS

- Mutual Impedance (Z_M), → $Z_M \rightarrow \dfrac{V_{OUT}}{I_{BEAM}}$

- Directional Sensitivity, $S_D \rightarrow \dfrac{V_{BEAM\ FWD}}{V_{BEAM\ REV}}$

  1, nondirectional

  >1, directional

- Displacement Sensitivity $S_X \rightarrow \dfrac{\partial\ (V_X)}{\partial\ x}$

- Linearity → deviation about BSL

  1 - 5% → 60% aperture

- Isolation → $V_X \rightarrow KV_Y$, $K \rightarrow -20/40$ dB

- Noise Temperature → $T_A = \dfrac{P_R}{K\ \Delta\nu}$, Kelvin

  P_R = Noise Power

  $K = 1.38 \times 10^{-23}$ J/K/Hz

  $\Delta\nu$ = Bandwidth

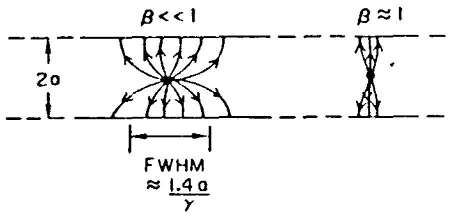
o LONGITUDINAL IMPEDANCE, Z/N → $\frac{\int V/\text{TURN}}{I_b}$

STRIPLINE → 1–4 ohms

o TRANSVERSE IMPEDANCE, Z_T → Small

o HARDNESS → MATERIALS MUST SURVIVE LARGE TOTAL DOSE OF RADIATION

o LOW β FACTOR → WALL CURRENT FIELD SPREAD AT WALL



BEAM SENSOR - FUTURE

- SPIRAL & SPIRAL ARRAY

- ARRAY OF LOOPS

- LIGHT GUIDEWAY + HOMODYNE AND $I_b(t)$ EFFECT ON FARADAY ROTATION

- BACK SCATTER RADAR AT $SUB_{MILLIMETER}$

- FORWARD SCATTER AT $SUB_{MILLIMETER}$

o <u>PROCESSOR OVERVIEW</u>

* WHAT TO PROCESS

* $\frac{d}{\Sigma}$ AGC & FEEDBACK

* $\frac{d}{\Sigma}$ BY FEEDFORWARD

Σ = sum
d = difference

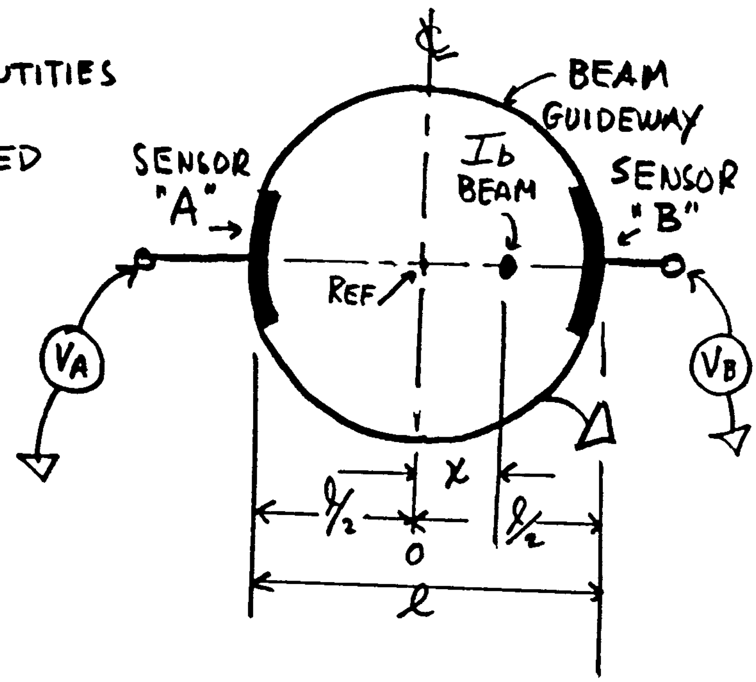
* $\frac{V_B}{V_A}$, RATIO BY CORRELATION

* VARIATIONS → ENVELOP DETECTOR, TIME MUX,
  UP/DOWN CONVERSIONS

WHAT TO PROCESS

1. DEVELOP SIMPLE MODEL
2. OPERATE ON QUANTITIES
3. CONCLUSIONS BASED ON CRITERIA:

DEVELOP AN ODD FUNCTION ABOUT $\chi=0$ WITHOUT AN INTENSITY DEPENDENCY



ASSUME

(a) GEOMETRY AS SHOWN

(b) LINEAR INDUCTION

(c) $V_A, V_B \propto I_b, \chi, \ell, V_p$

where

I_b = beam current

χ = X DISPLACEMENT VALUE

ℓ = plate separation

V_p = reference induction, beam max distance from opposite plate

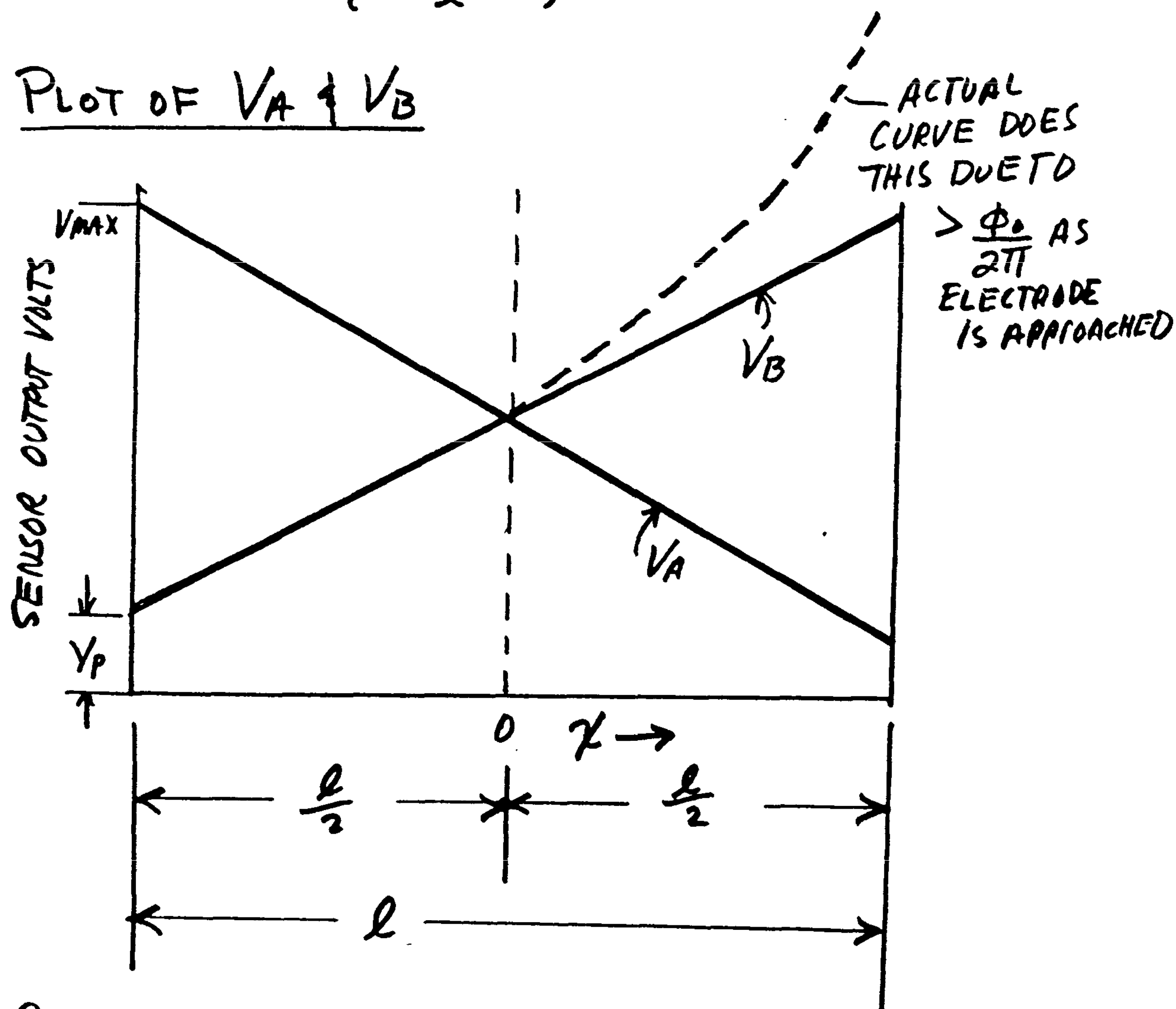
V_a, V_b = Sensor OUTPUT Voltage

Sensor Voltages

$$V_A = K I_b \left\{ \frac{\frac{l}{2} - x}{l} \right\} + V_P$$

$$V_B = K I_b \left\{ \frac{\frac{l}{2} + x}{l} \right\} + V_P$$

Plot of V_A & V_B



Operations on V_A, V_B

1. ADD .... (V_Σ)
2. SUBTRACT .... (V_d)
3. RATIO, LOG RATIO.... (V_R)
4. PRODUCT .... (V_x)

• SUM (V_Σ)

$$V_\Sigma = (V_B + V_A) = K_3 I_b \,,\; K_3 \text{ scaling constant}$$

- DOES NOT MEET CRITERIA – not odd and IT is proportional To I_b AND NOT to (X).
- V_Σ — CONSTANT WITH ONLY I_b as dependency
- Is it USEFUL ?---- YES, WHY?

- DIFFERENCE (V_d)

$$V_d = (V_B - V_A) = K_1 I_b \chi, \quad K_1 \text{ SCALING CONSTANT}$$

$$(\chi) = \frac{V_d}{K_1 I_b}$$

- V_d PROCESSING — DOES NOT MEET OVERALL CRITERIA, χ REMAINS PROPORTIONAL TO I_b ALTHOUGH χ = ODD ABOUT $\chi = 0$

- Recall V_Σ and DIVIDE $\rightarrow \left(\frac{V_d}{V_\Sigma}\right)$

$$\left(\frac{V_d}{V_\Sigma}\right) = \frac{K_1 \cancel{I_b} \chi}{K_3 \cancel{I_b}} = \left(\frac{K_1}{K_3}\right)\chi$$

$$\text{or } (\chi) = K_4 \left(\frac{V_d}{V_\Sigma}\right), \quad K_4 = \text{CONSTANT}$$

- THE SUM QUANTITY WAS USEFUL — TO SEE WHY, TURN PAGE.

THIS IS A REMARKABLE AND IMPORTANT RESULT

1. THE displacement is contained IN the DIFFERENCE-TO-SUM RATIO

2. The result is ODD ABOUT $X = 0$ due to Y_d changing SIGN

3. The result is insensitive to I_b

4. The slope of the result can be adjusted by manipulation of K_4

5. An electronic divider can be used To solve for x if dynamic range, response speed, frequency, and Spectral conditions permit.

6. MANY SYSTEMS OPERATE ON SENSOR SIGNAL IN THIS WAY

• RATIO (V_R)

$$V_R = \left(\frac{V_B}{V_A}\right) = \frac{K I_b P + V_p}{K I_b Q + V_p} \; ; \quad P = \left(\frac{\frac{l}{2} + x}{l}\right); \; Q = \left(\frac{\frac{l}{2} - x}{l}\right)$$

$$V_R = \left[\frac{1 + Kx}{1 - Kx}\right] = 1 + K2x + K2x^2 + 2Kx^3 \ldots$$

THIS IS ALSO A REMARKABLE AND IMPORTANT RESULT

1. The displacement x is independent of I_b
2. The displacement is contained in RATIO $\left(\frac{V_B}{V_A}\right)$
3. The $\log\left(\frac{V_B}{V_A}\right)$ is odd about $x = 0$ & LINEAR
4. An electronic processor can be used To solve for (x) AND CAN DETERMINE (x) in a few ms.
5. Meets CRITERIA
6. MANY "SUPER FAST" POSITION SYSTEMS OPERATE ON THIS TYPE OF PROCESSING.

- **PRODUCT (V_x)**

$$V_x = (V_A \times V_B) = \frac{K^2 I_b^2}{4} - \frac{K^2 I_b^2 x^2}{\ell^2} + K I_b V_p + V_p^2$$

- Complicated result
- DOES NOT MEET CRITERIA — EVEN FUNCTION ABOUT $x = 0$ i.e., $f(x) = f(-x)$
- Is it useful? Possibly if $\frac{d}{dx}\left[f(x)_{\text{even}}\right] \rightarrow f(x)$ odd.

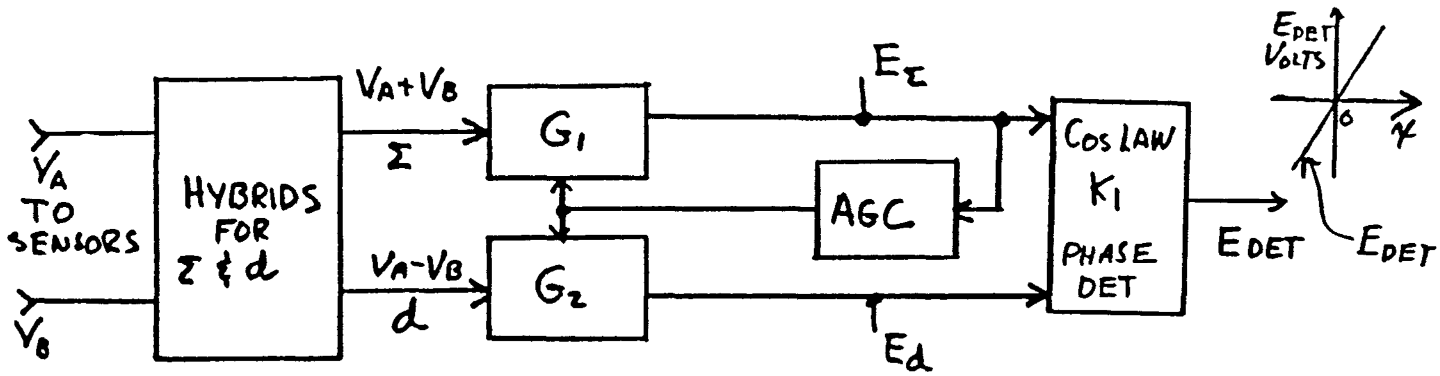
$$\frac{d}{dx}(V_x) = \left[\frac{-2K^2 I_b^2}{\ell^2}\right] x$$

- Answer — No! since $\frac{d}{dx}$ still depends on I_b^2 even though it has now become a desirable ODD function about $x = 0$

CONCLUSION:

1. USE $\left(\frac{V_d}{V_\Sigma}\right)$ processing or
2. USE $\left(\frac{V_B}{V_A}\right)$ RATIO PROCESSING
3. OTHER SIMPLE PROCESSES DON'T WORK!

$\left(\frac{d}{\Sigma}\right)$ PROCESSOR USING AGC AND FEEDBACK

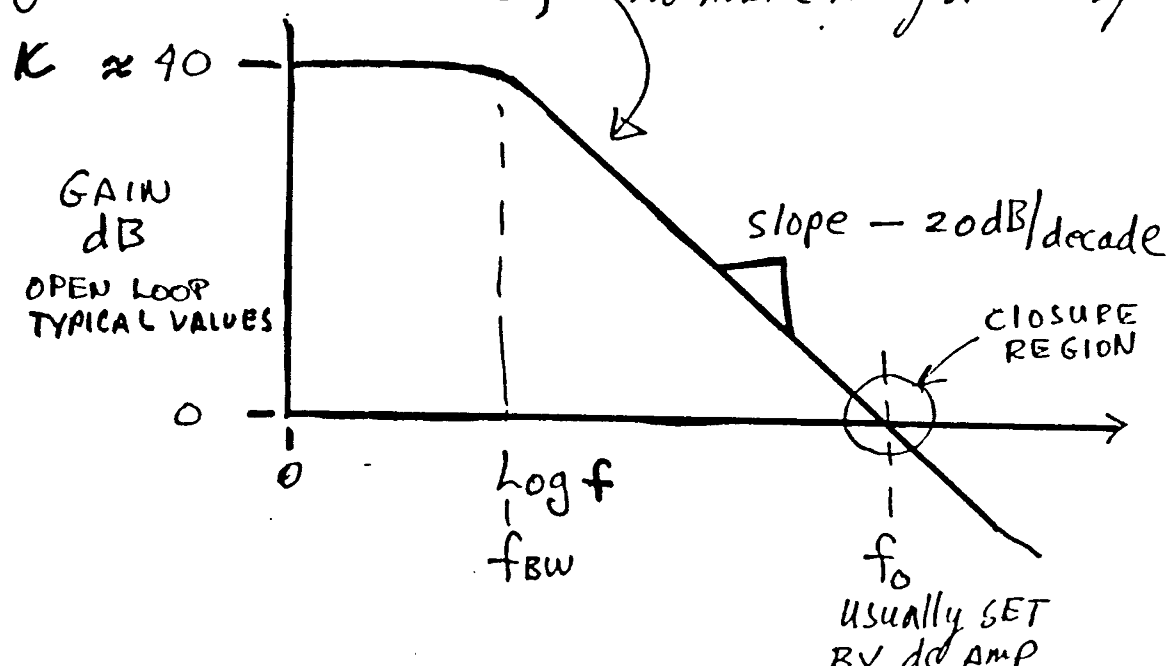


1. MATCH G_1, G_2 OVER OPERATIONAL DYNAMIC RANGE
2. FORCE $G_1 = G_2$ BY AGC ACTION AND E_Σ CONSTANT
3. $\Sigma G_1 = E_\Sigma$ and $d\, G_2 = E_d$
4. and $G_1 = \frac{E_\Sigma}{\Sigma}$ and $G_2 = \frac{E_d}{d}$
5. Since $G_1 = G_2$ $\frac{E_\Sigma}{\Sigma} = \frac{E_d}{d}$ or $E_d = \left(\frac{d}{\Sigma}\right) E_\Sigma$
6. Since E_Σ is CONSTANT(K) $\underline{\underline{E_d = K\left(\frac{d}{\Sigma}\right)}}$
7. Since these signals have $e^{j\omega t}$ dependence and the HYBRID(d) signal changes phase with beam displacement, $\pm\pi$, @ BEAM CROSSOVER
8. $E_{DET} = K_1 K\left(\frac{d}{\Sigma}\right) \cos\{\theta_{E\Sigma} - \theta_{Ed}\}$; odd FUNCTION

- $K_1 K$ — SLOPE CHANGER
- $\left(\frac{d}{\Sigma}\right)$ — DISPLACEMENT QUANTITY
- $\cos\{\theta_{E\Sigma} - \theta_{Ed}\}$ — SIGN CHANGER AT POINT WHERE BEAM CROSSES AXIS

- A COMPLICATION IN THE DIVISION PROCESS WHEN THE AGC-GAIN SLAVE METHOD IS USED.

- For stability in a feedback Systems the rate of Gain Closure toward $G = 1$ or 0dB should be < 40 dB/dec. say -20 dB/decade. ie., to make very stable system.



- If $f_o = 1MHz$, f_{BW} is $\frac{1MHz}{100} = 10KC$ for this example with response time $\tau \approx \frac{1}{f_{BW}} = 100\mu sec.$ a relatively long time = SLOW RESPONSE

SUM & DIFFERENCE ($\frac{d}{\Sigma}$) PROCESSOR FEEDBACK

ADVANTAGES

- o WIDE DYNAMIC RANGE
- o STABLE OPERATION
- o GOOD NORMALIZATION

DISADVANTAGES

- o COMPLEX CIRCUIT
- o REQUIRES MATCHED CHANNELS
- o SLOW FOR LARGE DYNAMIC INPUT RANGE
- o AGC COMPLICATIONS (MUST HAVE AVERAGER TO SMOOTH FEED BACK SIGNAL)
- o DIFFICULT IN REDUCING ERROR SINCE LARGE SIGNAL DIFFERENCE IN EACH CHANNEL

SUM AND DIFFERENCE ($\frac{d}{\Sigma}$) FAST SYSTEM

HOW DO YOU SOLVE THE SPEED PROBLEM?

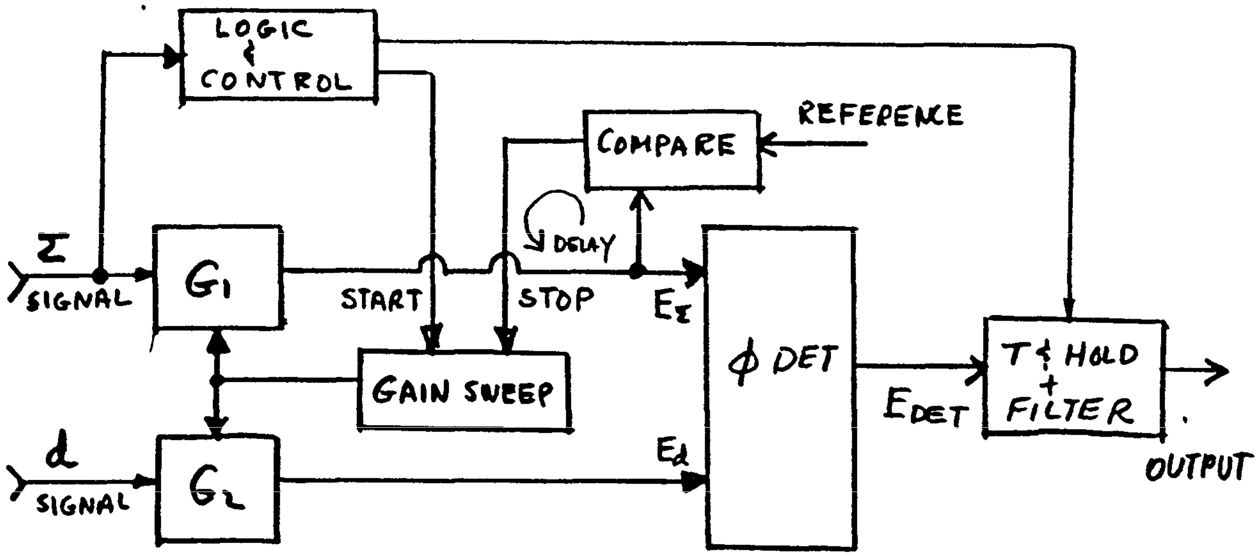
1. DESIGN FEEDFORWARD RATHER THAN FEEDBACK PROCESS.

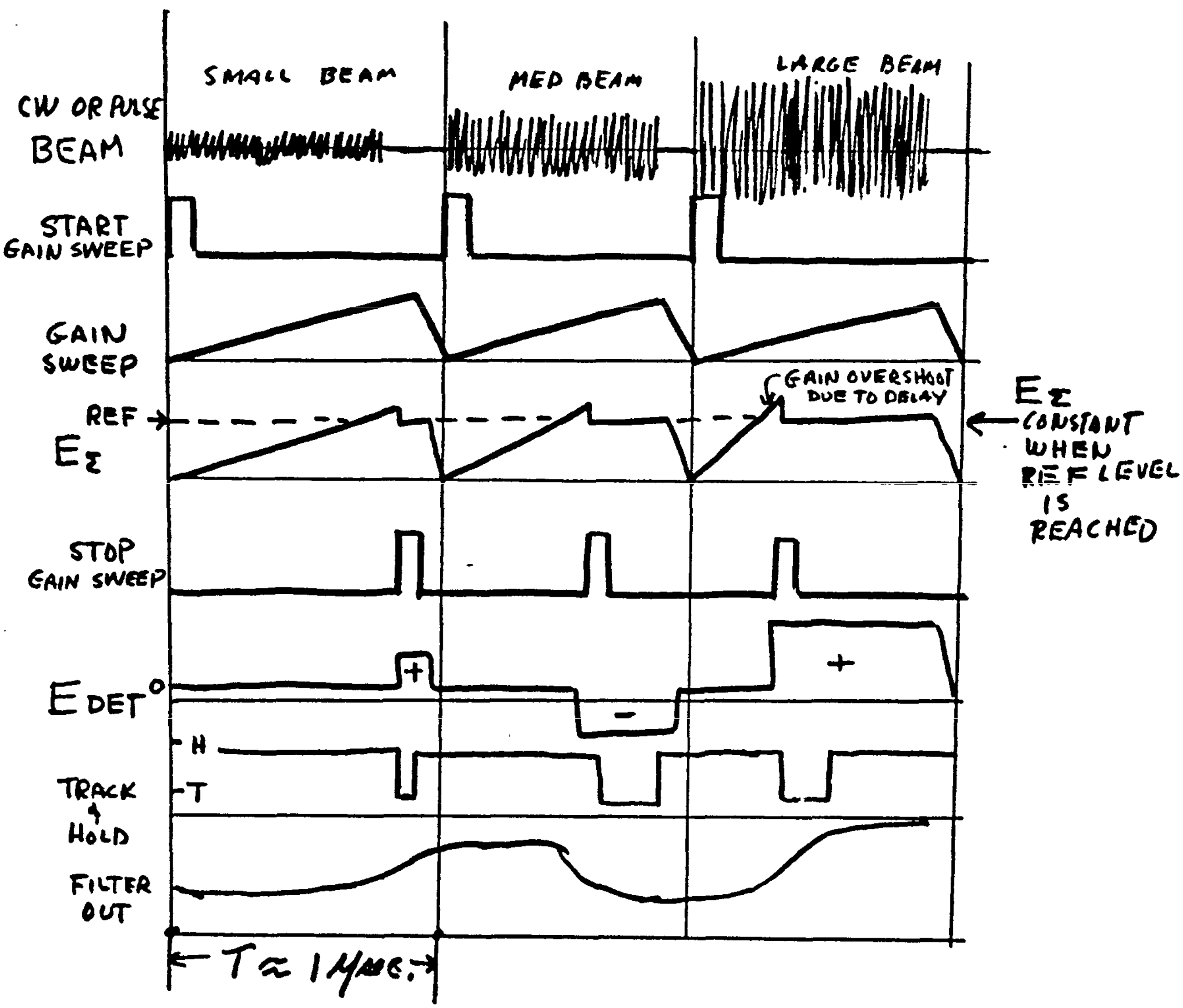
2. MAKE A "TIME MACHINE" TO CORRECT FOR THE MAJOR FEED-FORWARD ERROR.

3. USE GAIN SWEEP AND S & H TECHNOLOGY TO ADJUST GAINS AND PERMIT OUTPUT SAMPLING.

4. INTEGRATE (FILTER) THE T & H SIGNAL TO PRODUCE THE OUTPUT

$\left(\frac{d}{\Sigma}\right)$ PROCESSOR USING FEEDFORWARD AGC





SUM AND DIFFERENCE ($\frac{d}{\Sigma}$) PROCESSOR FEEDFORWARD

ADVANTAGES

- o FAST <1 SEC
- o GOOD NORMILIZATION < 1 dB
- o SINGLE PASS CAPABILITY
- o COMPACT
- o MINIMAL STABILITY PROBLEMS
- o COST EFFECTIVE RELATIVE TO SUM & DIFFERENCE TYPE (AGC)
- o RELATIVELY RELIABLE

DISADVANTAGES

- o MODERATE COMPLEXITY
- o REQUIRES MATCHED IF AMPS
- o REQUIRES TIME MACHINE

SUM AND DIFFERENCE ($\frac{d}{\Sigma}$) FEEDFORWARD

- TIME MACHINE

BECAUSE LARGE ERRORS CAN DEVELOP AS A CONSEQUENCE OF THE SWEEP STOPPING DELAYS A TIME MACHINE CIRCUIT SUBTRACTS OUT THE OVERSHOOT BY ANTICIPATING WHERE ACTUAL STOP POINT IS. THE GAIN OVERSHOOT QUANTITY (ΔG_o) IS:

$$\Delta G = \text{GAIN SWEEP RATE} \times \text{DELAY TIME}$$
$$\approx 1 \text{ dB IN PRACTICAL CIRCUITS}$$

RATIO PROCESSOR

* CORRELATOR
* DIFFERENTIAL CORRELATOR
* AM-PM CONVERTER GIVES $\Delta\tau$ FUNCTION
* MIXER GIVES PRODUCT FUNCTION
* AMPLIFIER GIVES INTEGRAL FUNCTION
* PROCESSOR BLOCK DIAGRAM
* TYPICAL DOWN CONVERTER PROCESSOR
* ADVANTAGES
* FAST PULSE TEST DEMONSTRATION

AT DIVISION

JOB

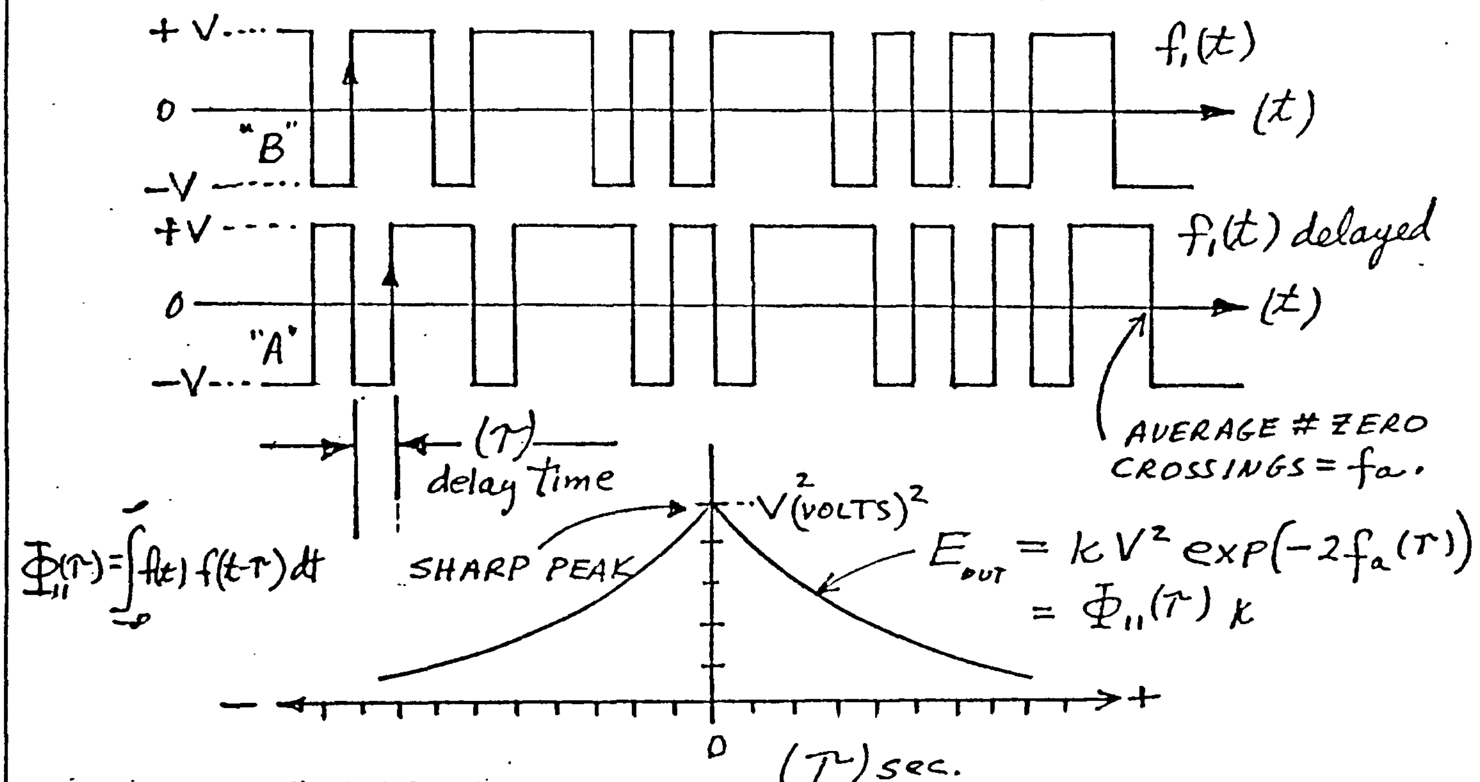
FIGURE - A8
CORRELATOR SIGNALS & BLOCK DIAGRAM

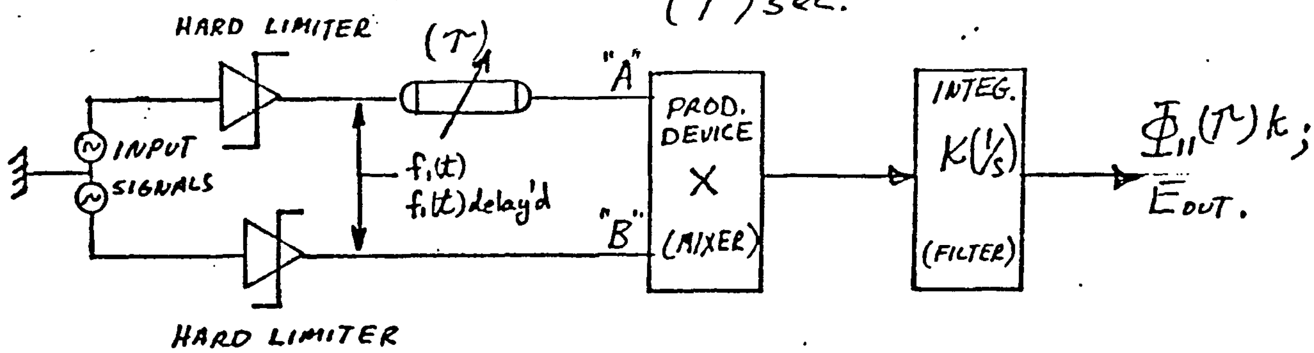
SHEET ~ OF ~

DATE 10/22/79

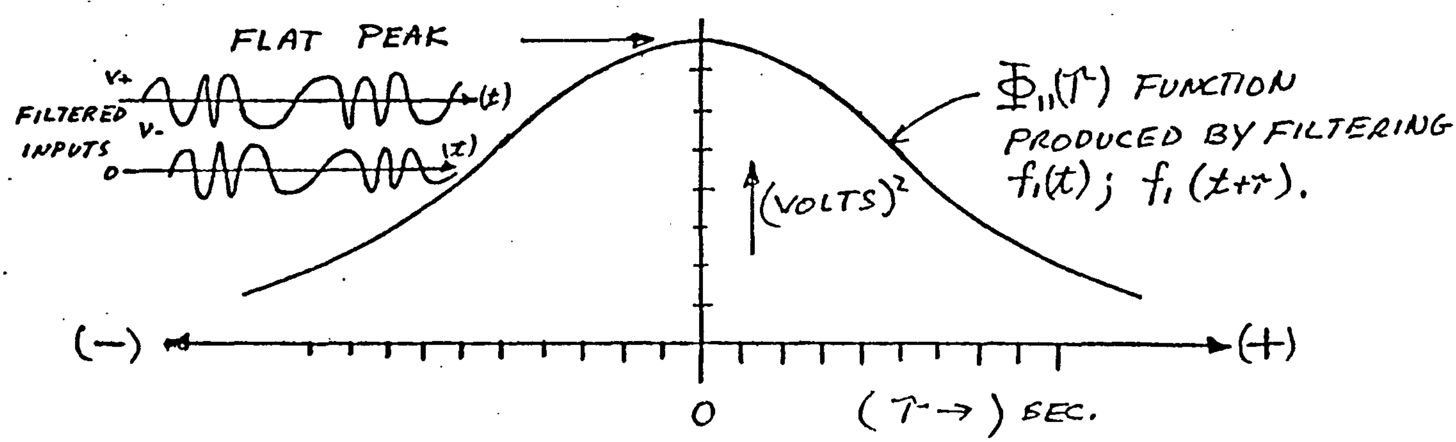
BY E.J.H. AT-3

CORRELATOR INPUT SIGNALS, $f_1(t)$.





CORRELATOR BLOCK DIAGRAM



FLAT PEAK $\Phi_{11}(\tau)$ FOR FILTERED INPUTS

AT DIVISION

JOB

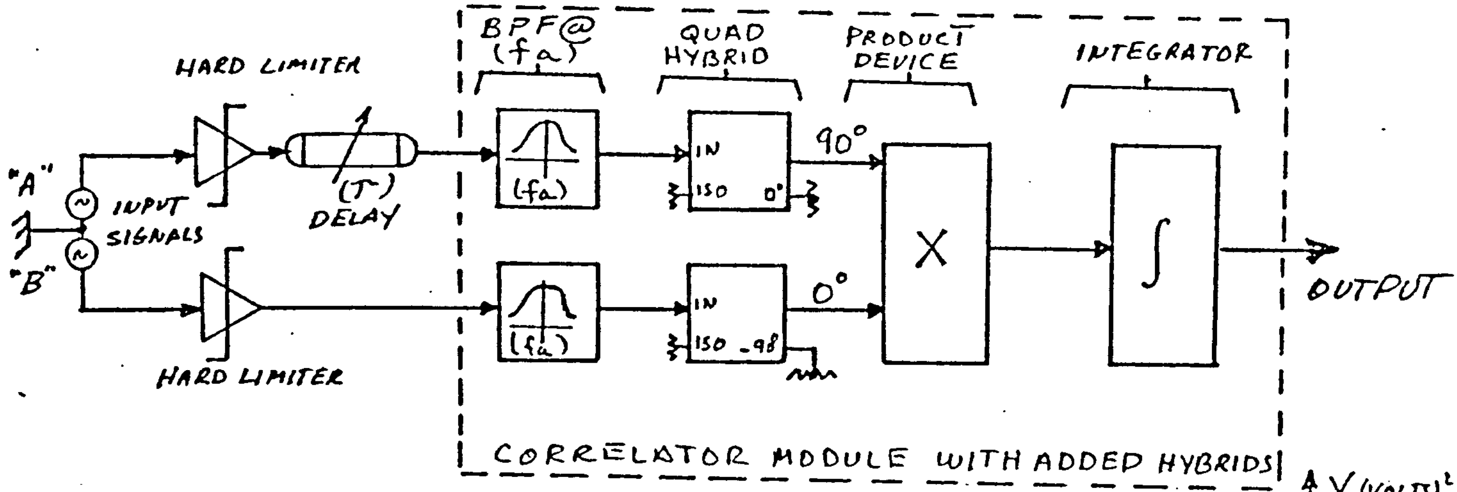
FIGURE - A_9

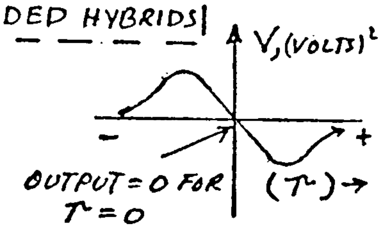
DIFFERENTIAL CORRELATOR & AMPLITUDE RATIO-TO-PHASE CONVERT.

SHEET ~ OF ~

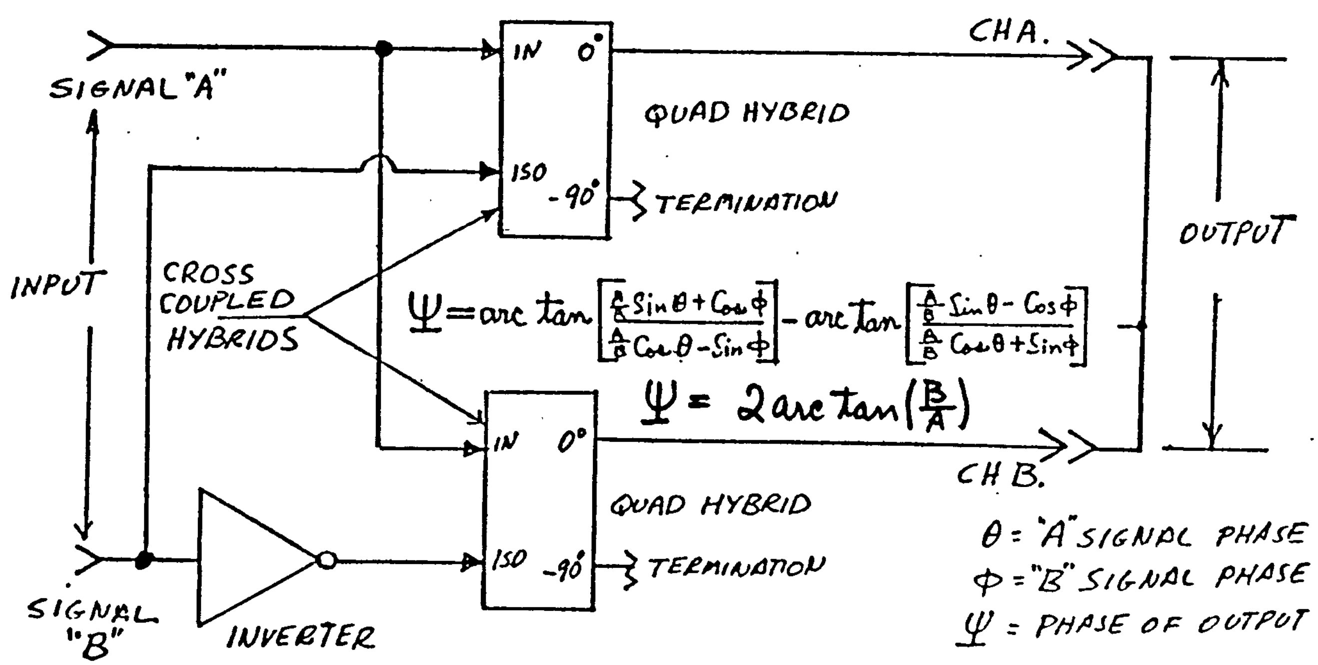
DATE 10/23/79

BY E.7.H AT-3





DIFFERENTIAL CORRELATOR
BLOCK DIAGRAM

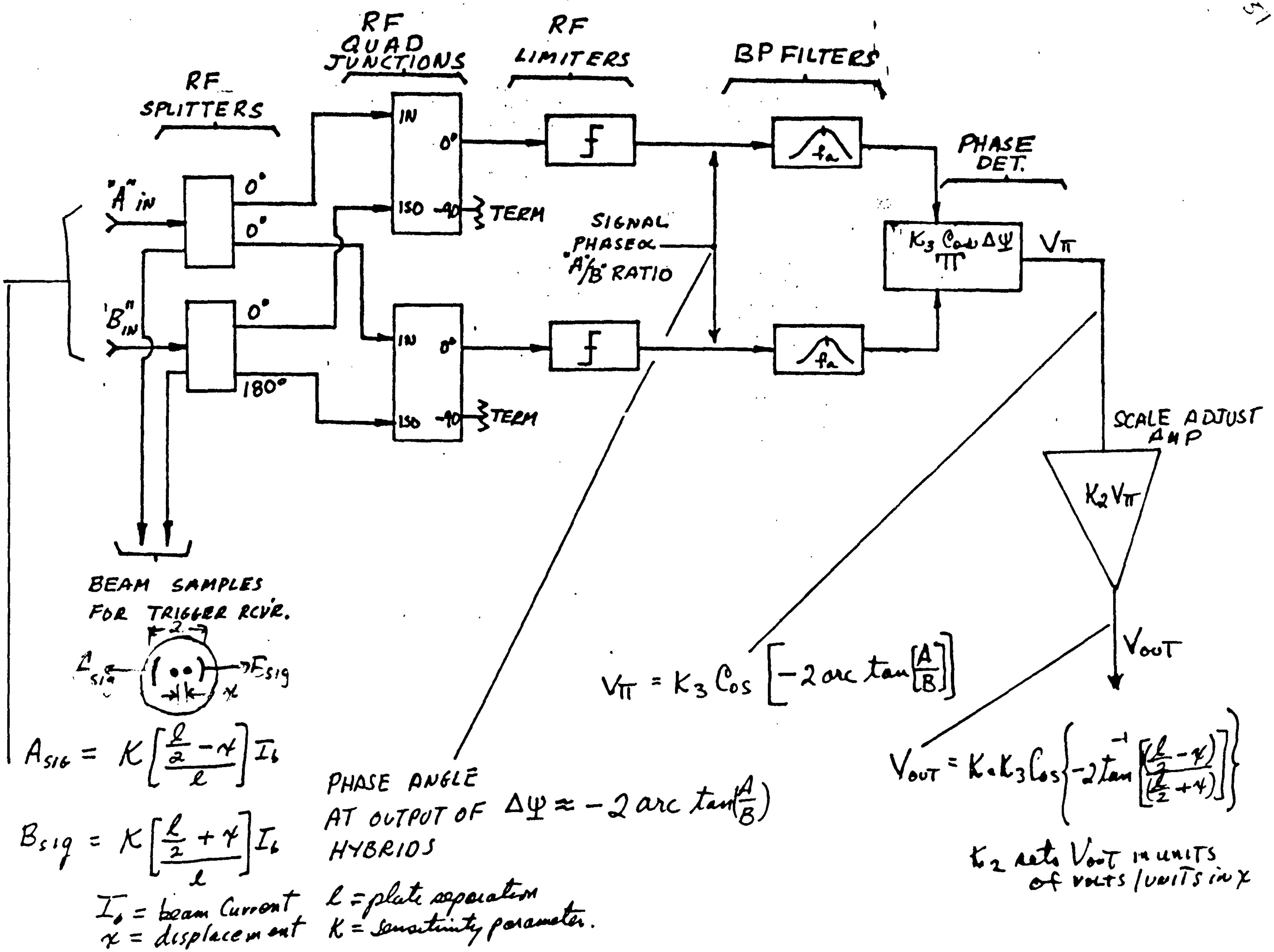


CIRCUIT TO CHANGE INPUT AMPLITUDE RATIO
TO PHASE/DELAY CHANGE

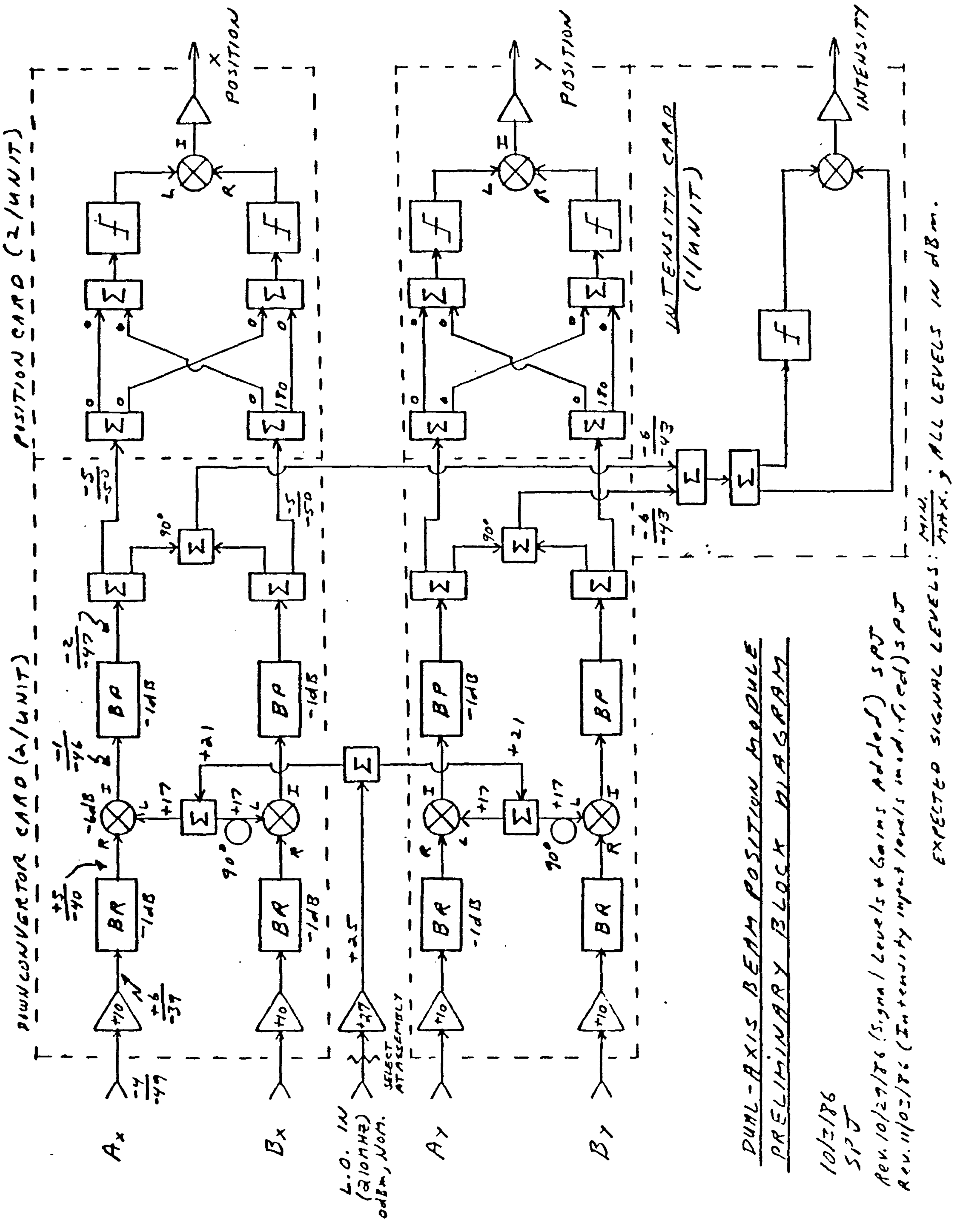
CORRELATOR PROCESSOR INSENSITIVE TO BEAM CURRENT (Ib)

11

51



Los Alamos Los Alamos National Laboratory Los Alamos, New Mexico 87545 A T DIVISION	JOB EXAMPLE OF RATIO PROCESSOR FOR DUAL SENS + INT.	Sheet Of Date By



ADVANTAGES OF RATIO PROCESSING

- o SUPER FAST →ANSWER AVAILABLE IN 10-20 NS.

- o BUNCH BY BUNCH PROCESSING POSSIBLE

- o NO AGC OR GAIN SWEEP CIRCUITS REQUIRED

- o REDUCED ERROR DUE TO SMALL DIFFERENCES IN A, B, SIGNAL LEVEL

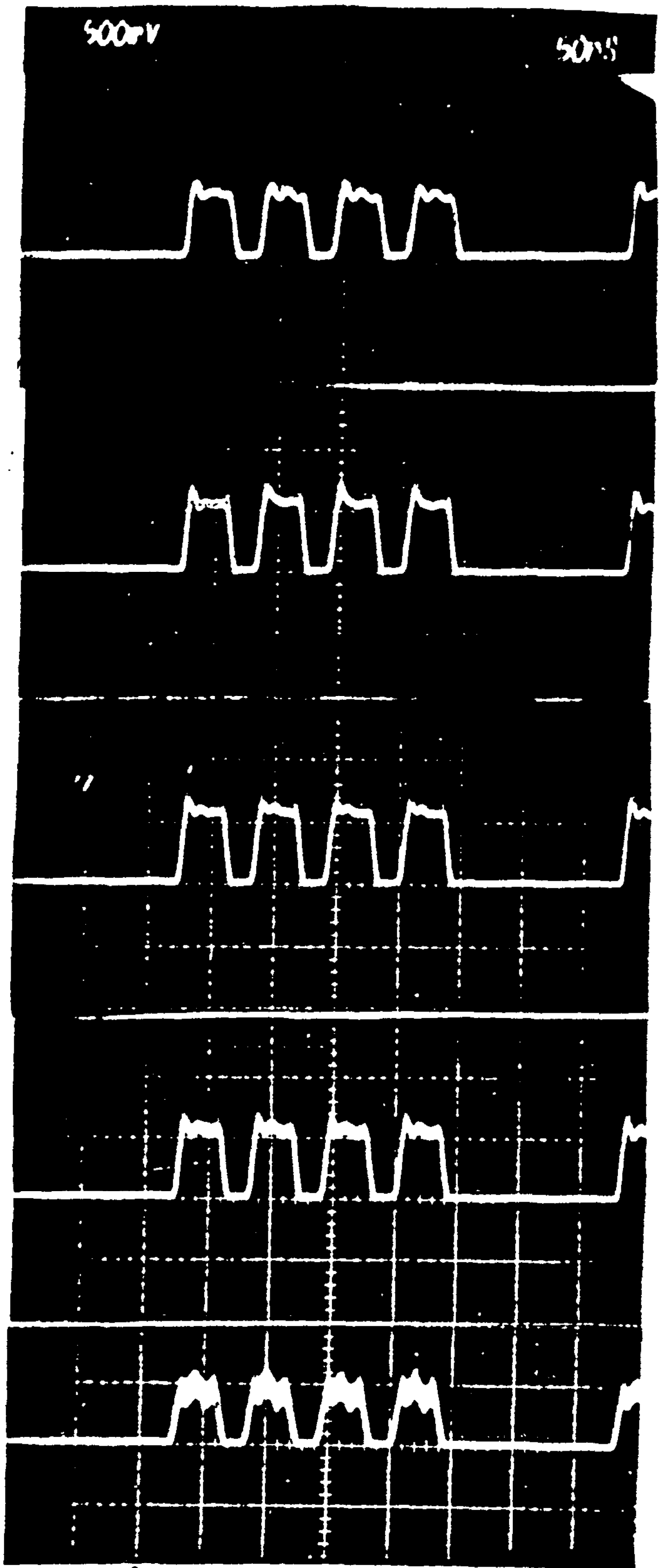
- o VERY STABLE - ALMOST NO OFFSET OR DRIFT COMPONENT

- o EASILY USED WITH UP/DOWN CONVERSIONS TO OTHER THAN BEAM FUNDAMENTAL FREQUENCY.

- Easily configured for intensity output
- Not super sensitive to input differential phase error
- Very versatile relative to beam temporal format
- Can be made to operate over very wide dynamic ranges → 60 dB
- Can function on noise-like signal if required
- Very cost effective in large numbers

EXAMPLE (1?)
RATIO PROCESS

INTENSITY RELATED
BEAM POSITION PROCESSOR PERFORMANCE
SHORT BUNCH MODE



0 dB REF
≈ 5mm OFF AXIS

−10 dB

−20 dB

−30 dB

−40 dB

↑
t=0 Total thruput delay = 30 ns.

PART IV DOs AND DONTs

*DO

- o ESTABLISH OVERALL REQUIREMENTS AND SPECS EARLY

- o DETERMINE LARGEST APERTURE OVER WHICH DATA IS REQUIRED

- o DETERMINE WORST CASE DYNAMIC RANGE

- o ESTIMATE SNR, WORST CASE

- o INSULATE SENSOR FROM BEAMLINE IF POSSIBLE

DO

- o DEVELOP SENSOR ON BASIS OF
  - * SPACE
  - * DRIVING CAPABILITY
  - * SENSITIVITY TO DESIRED FUNCTION
  - * MINIMIZE ELECTRONICS

- o USE SUPER GOOD CABLES WITH LOW LOSS AND VSWR

- o KEEP ELECTRONICS SHIELDED AGAINST RADIATION

- o USE INDIVIDUAL CHANNELS RATHER THAN MUX

- o DESIGN FOR COMMISSIONING, MAINTENANCE, AND NORMAL OPERATION

DON'T

- Multiplex unless speed is unimportant

- Use sensors having high Z/N, determine Z/N budget 1st

- Use unmatched vacuum feedthrus

- Underestimate dynamic range or speed requirements especially for diagnostic and machine studies

- Try to couple many other measurements into the design for the position System, Intensity and Position OK

DON'T

- o SELECT INTERCONNECTIONS ON BASIS OF COST ONLY

- o USE $\frac{d}{\Sigma}$ PROCESSING IF RATIO PROCESS WILL WORK

- o USE AGC IF PROCESSING SPEED IS VERY IMPORTANT

- o PUT SOLID STATE ELECTRONICS AT OR ON THE BEAMLINE

SUMMARY

- o MAKE CAREFUL SYSTEM STUDY BEFORE SELECTION OF PROCESS.

- o AGC PROCESSOR FOR DIVISION MAY BE SLOW (100 μSEC-TO-MS)

- o USE FEED FORWARD FOR FASTER RESPONSE IN AN AGC CONFIGURATION.

- o "TIME MACHINE" CIRCUITS CAN REDUCE ERRORS IN AGC SYSTEMS.

- o DYNAMIC RANGES IN BEAM POSITION SYSTEMS MAY BE O.K. EVEN AT 60 - 70 dB IE., 1,000:1-TO - 3,000:1

- o FASTEST PROCESSING DEVICE IS DIRECT DIVISION VIA AM-PM CONVERTER AND CORRELATOR.

- o HYBRID PASSIVE DEVICES CAN BE USED TO MAKE THE POSITION VALUE APPEAR AS THE LOG RATIO OF THE SENSOR VALUES.