Project X

Fermilab

Status of Microwave Measurements in the Main Injector

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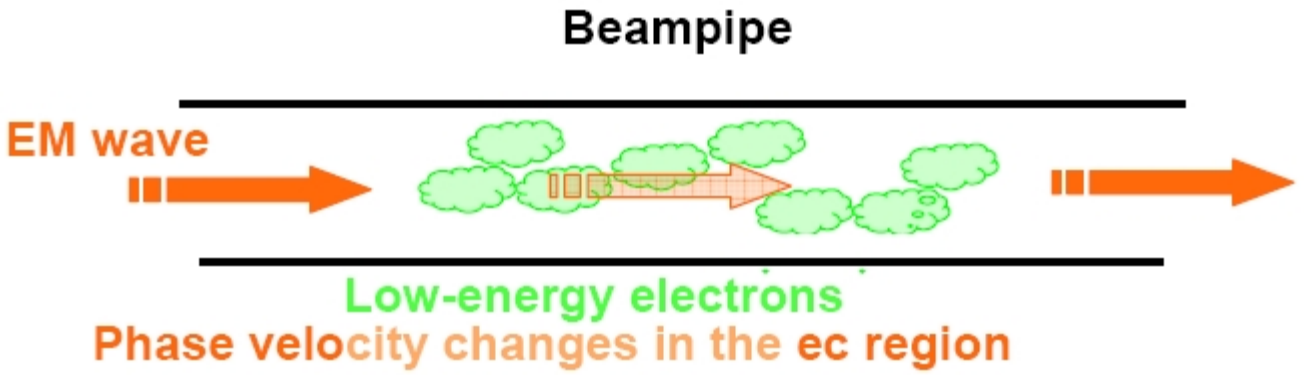
Project X Collaboration Meeting

Sep 11, 2009

Microwave Transmission Theory

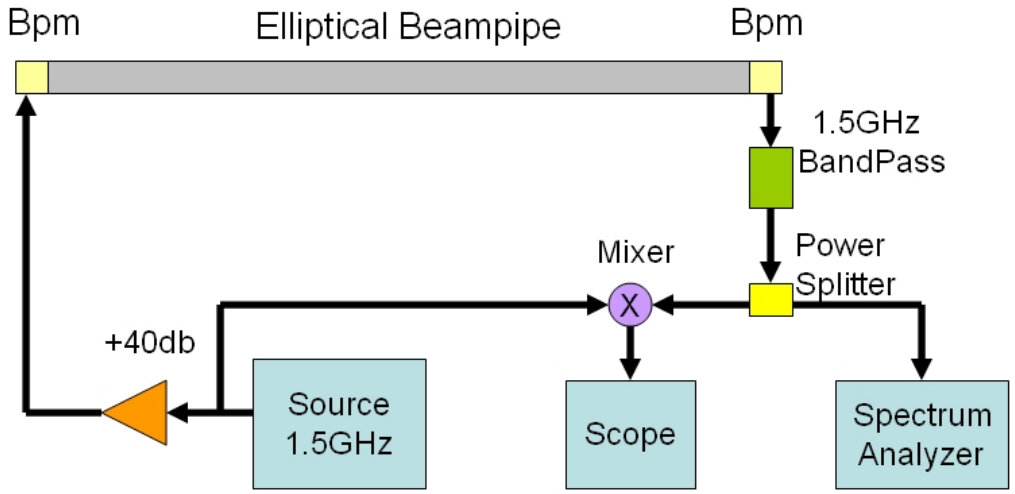


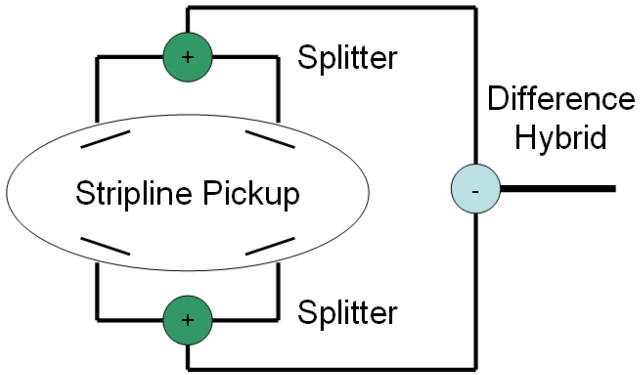
From plasma physics, expect a microwave travelling down a waveguide to experience a phase shift due to a homogeneous plasma
From the microwave dispersion relation

$$k^2 = \frac{\omega^2 - \omega_c^2 - \omega_p^2}{c^2} \quad \Rightarrow \quad \frac{\Delta\phi}{l} = \frac{\omega_p^2}{2c\sqrt{\omega^2 - \omega_c^2}}$$

For an electron cloud $\omega_p^2 = 4\pi\rho_e r_e c^2$ is proportional to *e* density

Measurement Setup

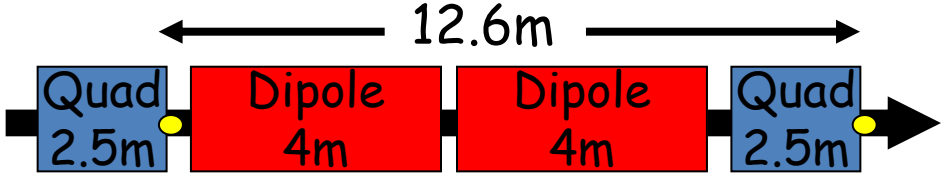




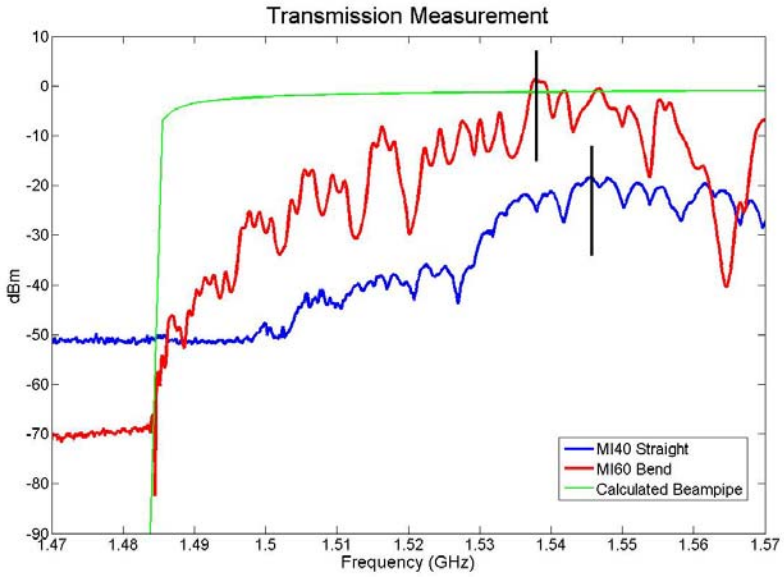
- Made three different measurements of the phase shift
  - Measure sideband spectrum of 1.5GHz carrier with SA
  - For phase modulation of amplitude β, sideband dbc = 20log(β /2)
  - Measure 1st sideband over a full MI ramp (800ms) in zero span mode with SA
  - Mix down to baseband and record IF with deep memory scope (10MHz BW)
- Pickup connections to optimize coupling to TE_{11} mode
  - Measure -20db transmission for two pickups and 15m of beam pipe
  - Cutoff for beam pipe is just below 1.5GHz

Previous Measurement Locations

MI60 Bend Region

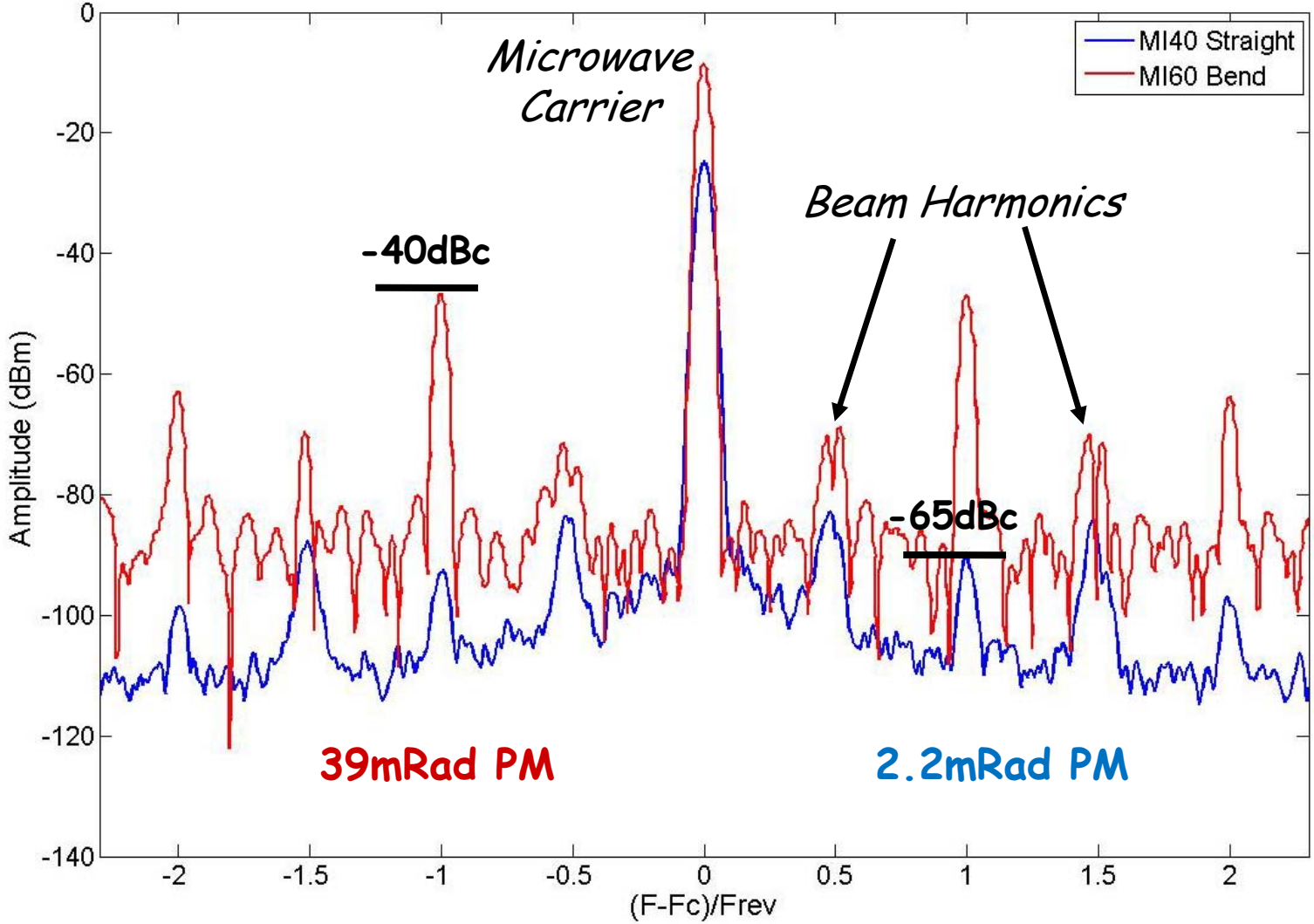


MI40 Straight Region



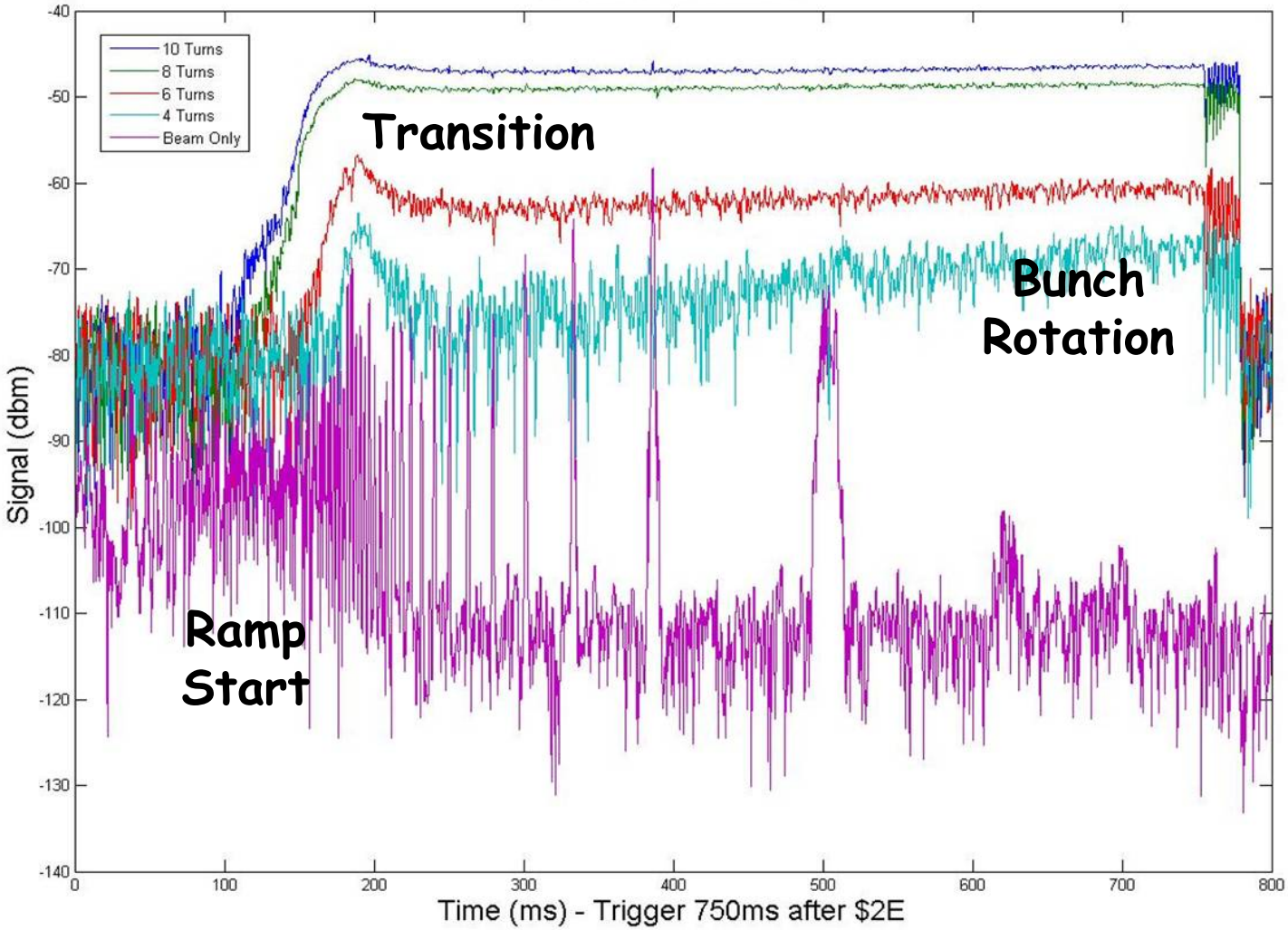
- At MI60 Bend Region able to use spare Heliax cable
- At MI40 Straight Region have to use RG8 bpm cable
  - See an addition 20db of attenuation on transmitted signal
  - Appear to get coupling between the cables
  - Put the 40db drive amplifier in the tunnel at this location

Sideband Spectrum Measurement

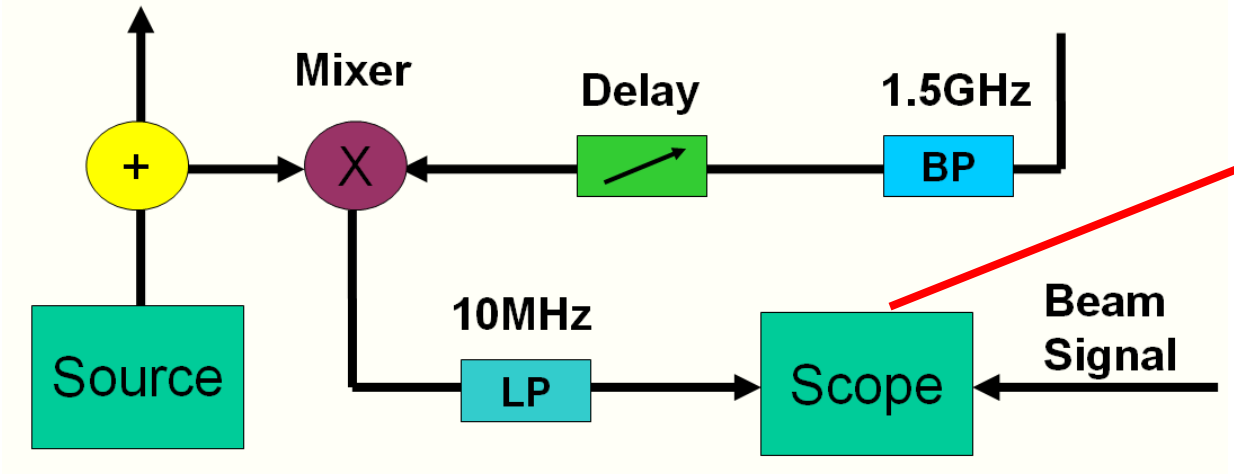


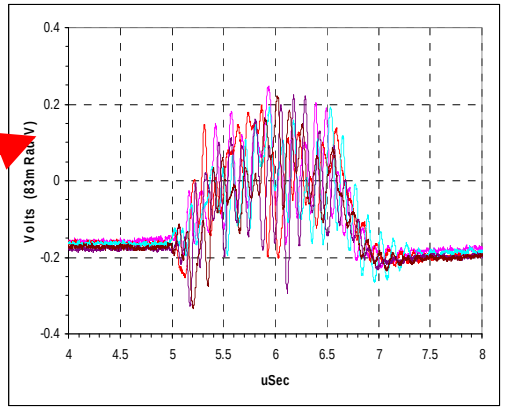
Zero Span Sideband Measurement

MI60 Bend



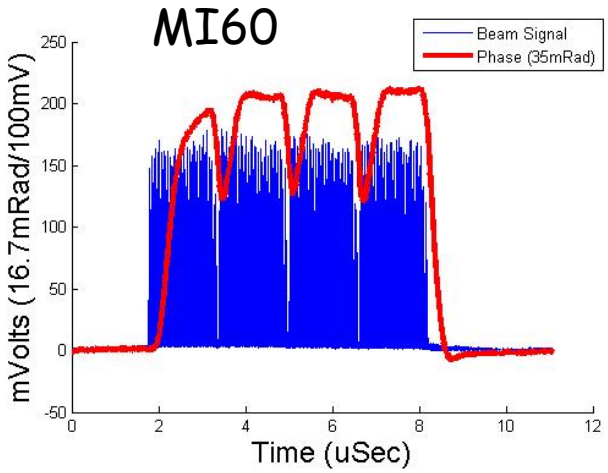
Direct Phase Shift Measurement

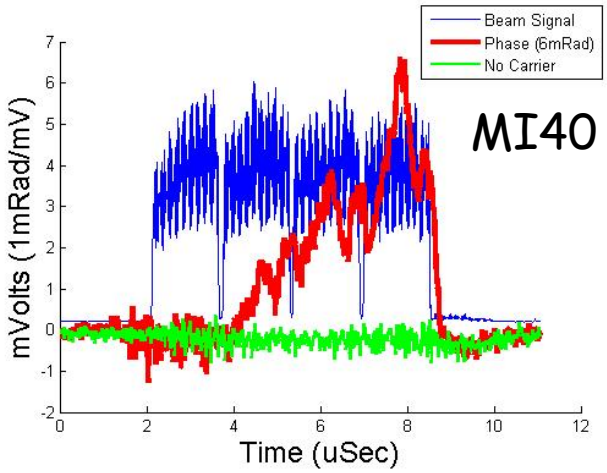


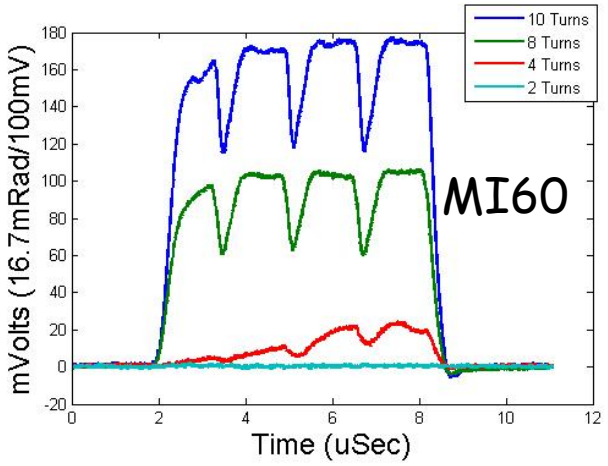


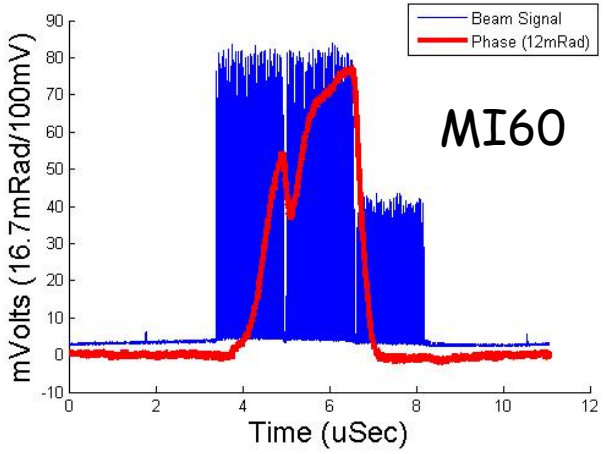
- Mix the transmitted microwave signal to baseband
  - Use the delay to effect 90° phase shift (zero DC offset)
  - Theoritically, should only see PM modulation as AM cancels
- Scope aquires from 2ms to 20ms sampling at either 500MS/s or 100MS/s respectively
  - Expect eCloud induced phase shift to be the same each turn
  - The beam harmonics behave as noise which averages away
    - Use 100 turn average at MI60 and 1700 turns at MI40
  - Size of the beam harmonics impacts the dynamic range

Direct Phase Shift Results

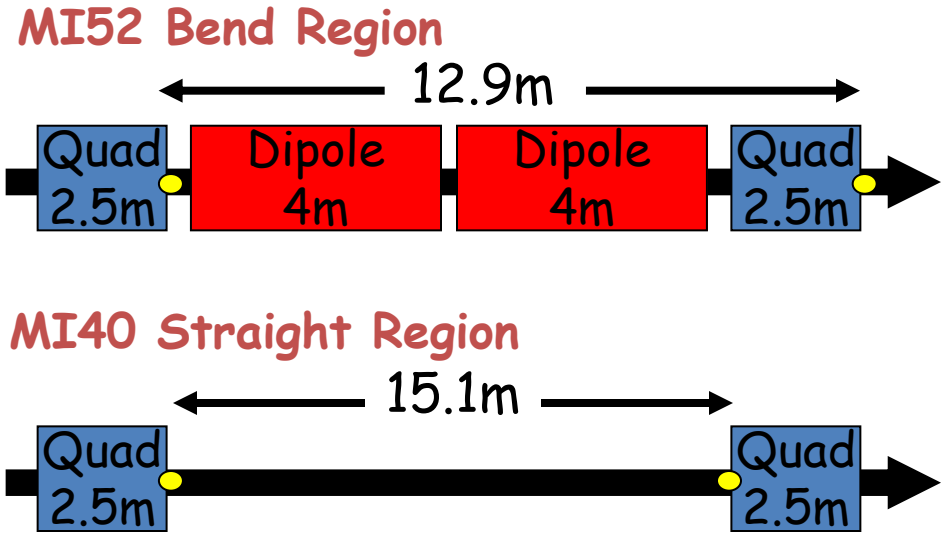


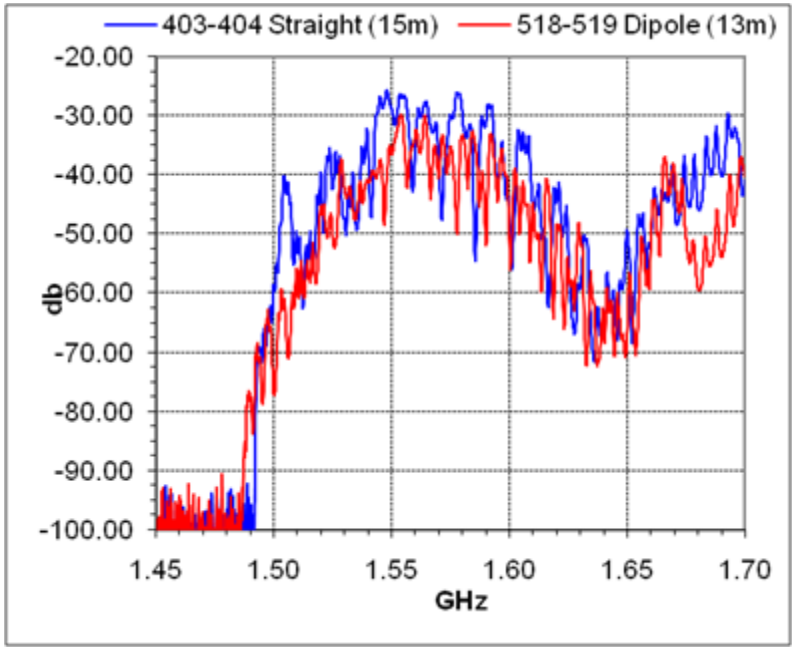






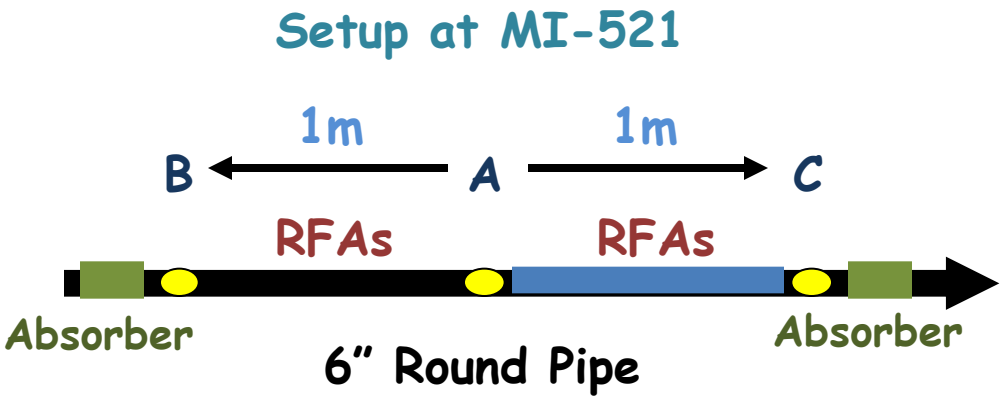
New Dedicated Pickups

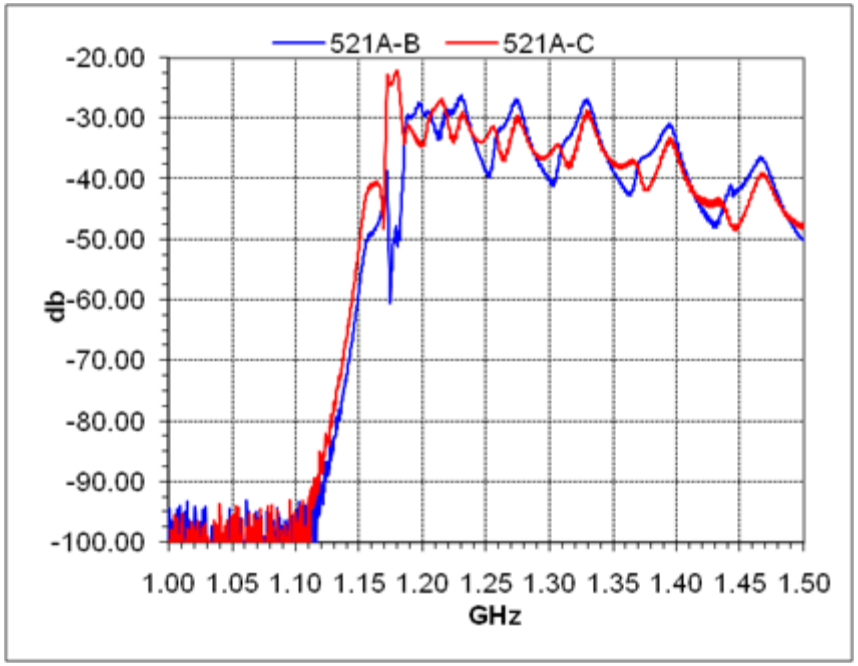




- Dedicated BPMs installed at MI52 Bend and MI40 Straight
  - Standard elliptical beam pipe and pickups
  - Completely field free at MI40 straight
- Good quality heliax cable pulled for each BPM
  - Expect improved sensitivity for MI40 Straight

Coated Pipe/RFA Comparison





- Three Large Aperture BPMs have been installed around 1m long test pipes at MI-521
  - Cutoff for the 6" round pipe is just below 1.2GHz
  - As measured phase shift is proportional to length ➡ -23db sensitivity
- Will provide direct comparison with RFA
  - Expect to be very useful in understanding $\Delta\varphi$ ➡ *e* density

Summary and Plans

- Crosscheck Measurements and Sensitivity at New Locations
  - Can now make measurements at each location under similar conditions rather than weeks or months apart
  - Expect stronger signals before conditionning
- Demodulate transmitted signal to separate PM & AM
  - Verify we are observing Phase Modulation
  - Verify expectation of no Amplitude Modulation
- Calibrate phase shift to electron density
  - Comparison with RFA measurements
  - Comparison with simulation results
- We welcome anyone interested in helping!