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Sideband Analysis for AC Line Noise and Klystron Instabilities on the Storage Ring RF Systems

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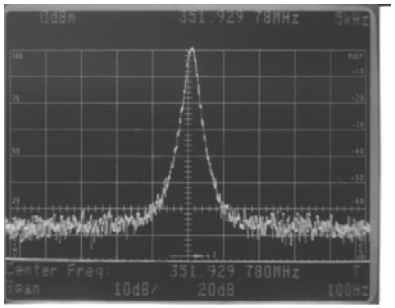
Presentation Outline

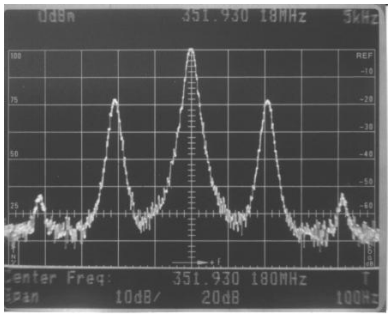
1. Methods of sideband generation.
2. Sidebands related to the ac line.
3. Sidebands generated by klystron instabilities.
4. Addressing sideband issues.
5. Conclusion

Sideband Generation

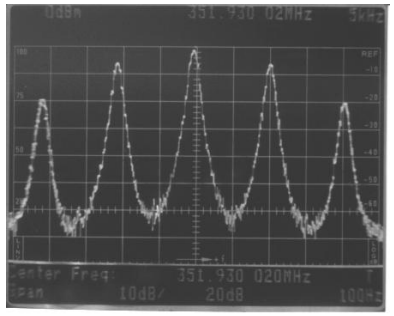
- Sidebands are generated whenever an rf carrier is amplitude, frequency, or phase modulated:

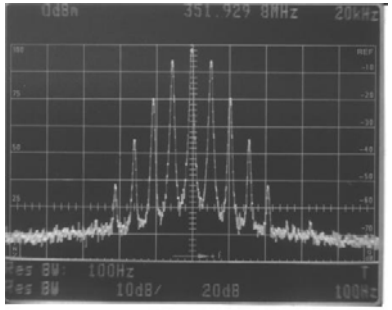


UNMODULATED 352-MHz CARRIER



352-MHz CARRIER, 25% AMPLITUDE MODULATION, 1KhZ MODULATION FREQUENCY





352-MHz CARRIER, FREQUENCY MODULATION, 1KHz MODULATION FREQUENCY, 1KHz FREQUENCY DEVIATION

- Sideband energy can couple into the storage ring beam and cause elevated beam motion or beam losses.

Sideband Generation

- **Klystrons are natural rf phase modulators due to the time of flight of the electron beam, which varies with cathode voltage:**

  → *The 352-MHz/1MW CW klystrons will produce approximately 7° rf phase shift for every 1kV change in cathode voltage, and approximately 4° rf phase shift for every 1 ampere change in beam current.*

- **Power supply ripple (typically related to the 60Hz ac line) results in amplitude and phase modulation of the klystron rf output:**

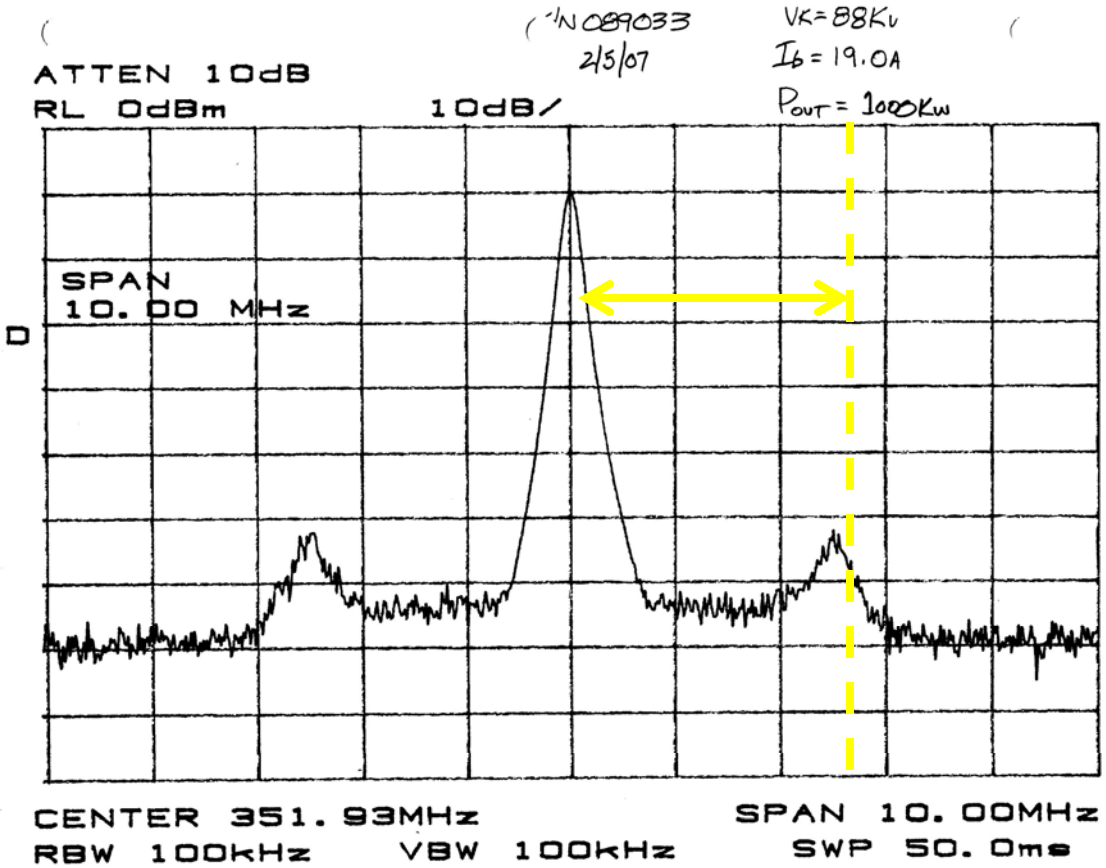
  → *If uncorrected, the normal 950v p-p ripple on the output of the UVC power supply will cause the klystron to produce excessive phase and amplitude modulation.*

  → *Two LLRF phase loops reduce the phase modulation due to power supply ripple to approximately 1° p-p.*

  → ***Predominate ripple frequency from UVC HVPS is 360Hz, but SCR imbalance can generate 60Hz, 120Hz, and 180Hz.***

Normal Klystron Output Spectrum

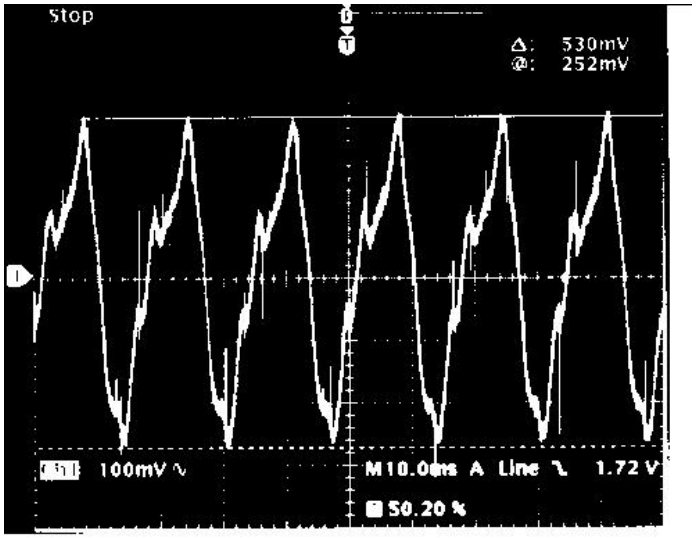
- **A normal klystron output spectral display:**



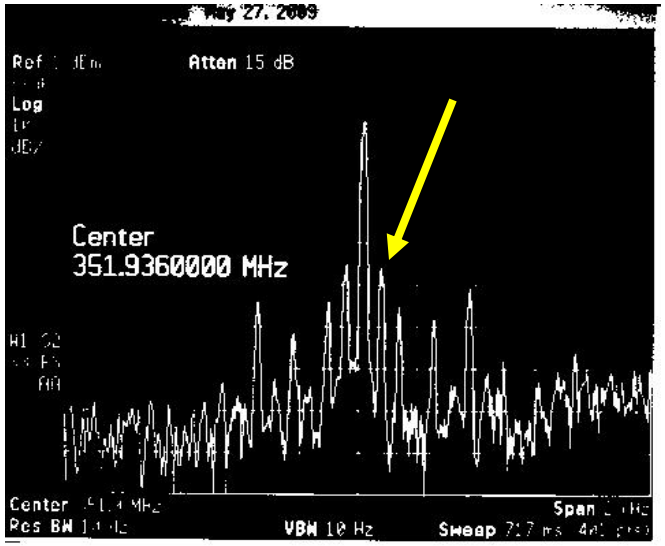
Small sidebands at the C1 and C2 difference frequency are normal!
sometimes only the upper sideband is seen.

Sidebands Related to the AC Line

- **Excessive ripple on the output of the HVPS will result in excessive sideband level and corresponding phase jitter:**



5kV p-p ripple on output of RF1 –
almost five times normal amount, 60Hz predominate frequency



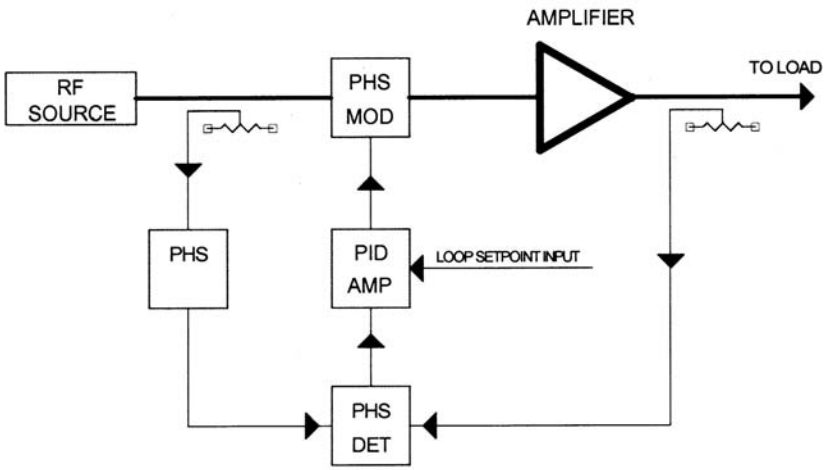
60Hz sideband level
at approximately -35dBc!

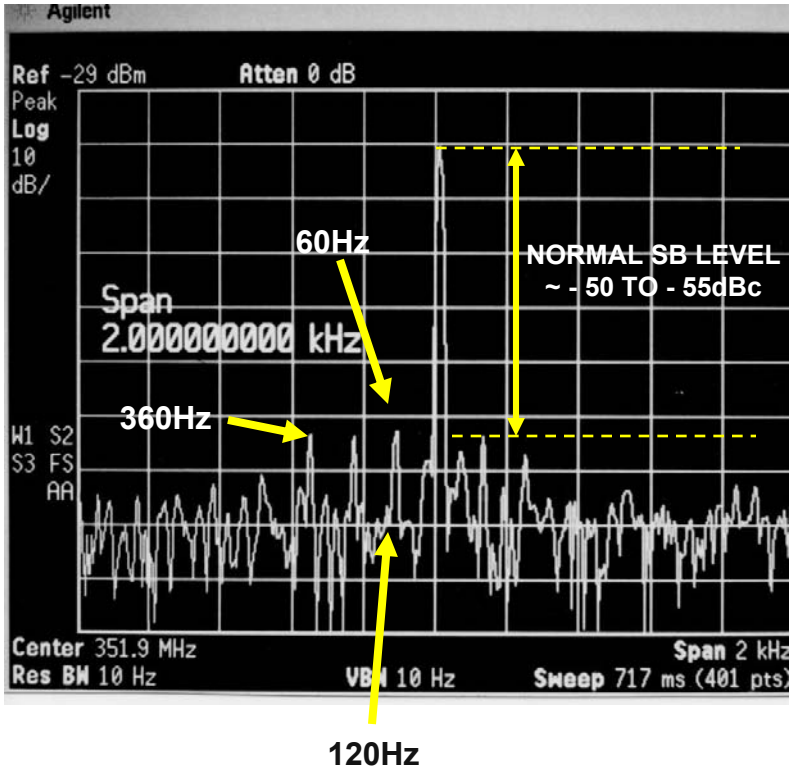
These operating parameters resulted in excessive beam motion!

Sidebands Related to the AC Line

- Nx60Hz sidebands are generated by the klystron due to ripple on the output of the HVPS. The sideband power is a result of both amplitude and phase modulation at the ripple frequencies.

- Phase loops limit the resulting phase modulation to a level tolerable by the storage ring beam:



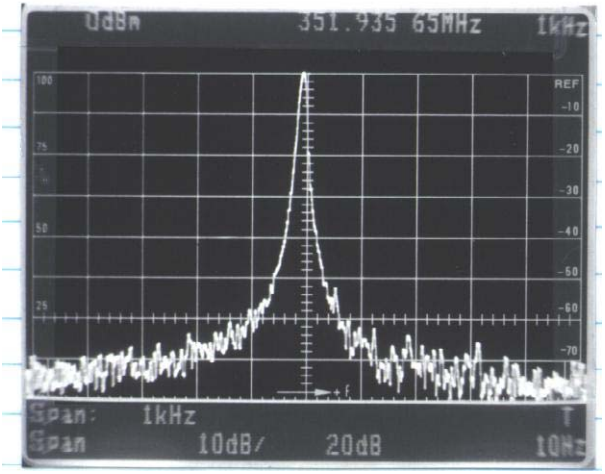


SR RF phase jitter specification is 1º p-p, which corresponds to ~ -50dBc sideband level

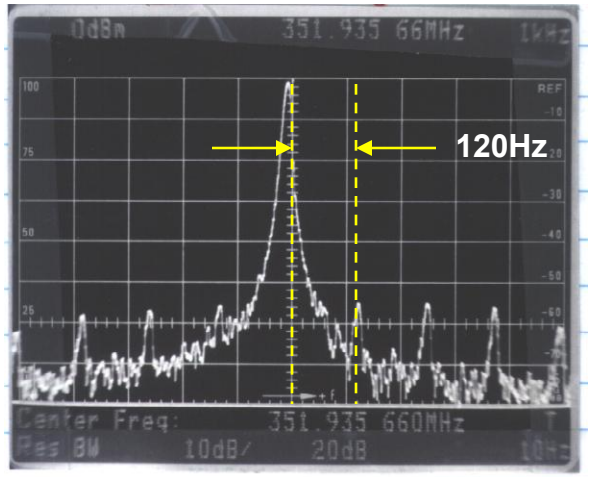
Sidebands Related to the AC Line

- **Excessive power supply ripple in synthesizers, reference time base signals, or rf source distribution amplifiers can inject sideband energy into the rf systems, which is then amplified by the klystrons.**

One case of excessive beam motion was caused by 120Hz sidebands on the output of the main 352-MHz synthesizer. The source of the 120Hz was power supply ripple in the 10MHz reference OCXO source due to bad electrolytic filter capacitors in a 24VDC linear power supply:



NORMAL OUTPUT OF 352-MHz MAIN SYNTHESIZER



ABNORMAL 120Hz SIDEBANDS ON OUTPUT OF THE 352MHz MAIN SYNTHESIZER

Sidebands Generated by Klystron Instabilities

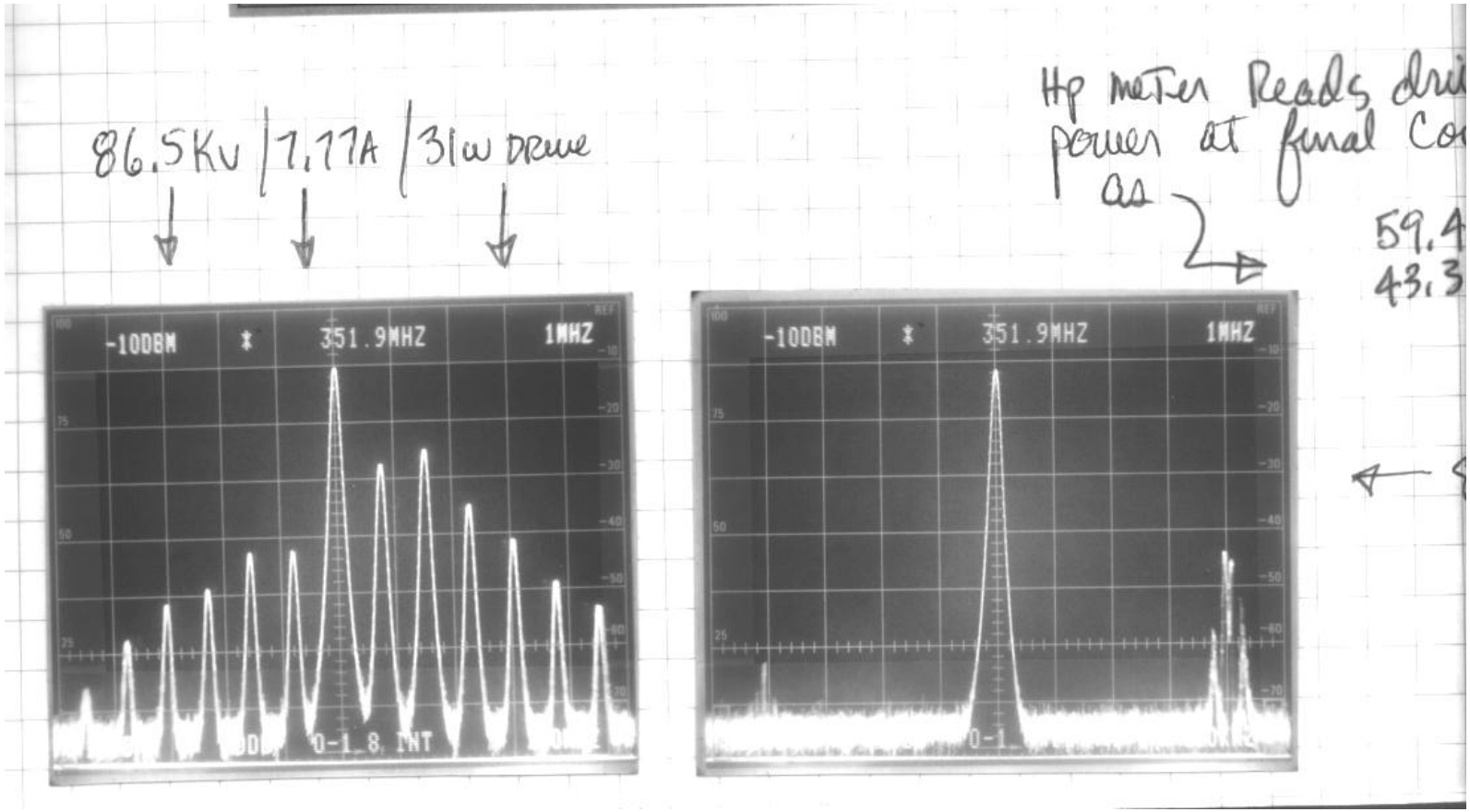
- **The relatively common "back streaming" electron instability typically generates very strong sidebands above and below the carrier, with a frequency spacing approximately equal to the difference between the input cavity and cavity #2 resonant frequencies.**

→ "Backstreaming" sidebands can remain stationary, or move about in frequency….. either condition can result in a beam loss.

Klystron-produced sidebands, caused by electron instability in the Thales klystron at RF2 (s/n 089041). ***Note the 2MHz spacing between the sidebands.***

Sidebands Generated by Klystron Instabilities

- Cavity multipactor discharges in klystron cavities can result in sideband generation. The sideband frequency is determined by the transit time of the multipactor path.



Sidebands produced by Thales TH2089A – s/n 089026, caused by a spot of cathode barium on one of the input cavity nosecones.

Addressing Sideband Issues

- Investigate complaints of excessive beam motion by looking for excessive sideband energy in the output of rf stations.
- If excessive sidebands are seen at frequencies related to the ac power line (60Hz, 120Hz, 360Hz), check power supplies feeding active LLRF signal path equipment for excessive ripple. The sideband frequency may lead you to the source:

  → **60Hz typically comes from a single-phase source such as HVPS heater supplies or SCR imbalance**

  → **120Hz could mean open or leaky filter capacitors in a full-wave rectifier somewhere in the LLRF signal path**

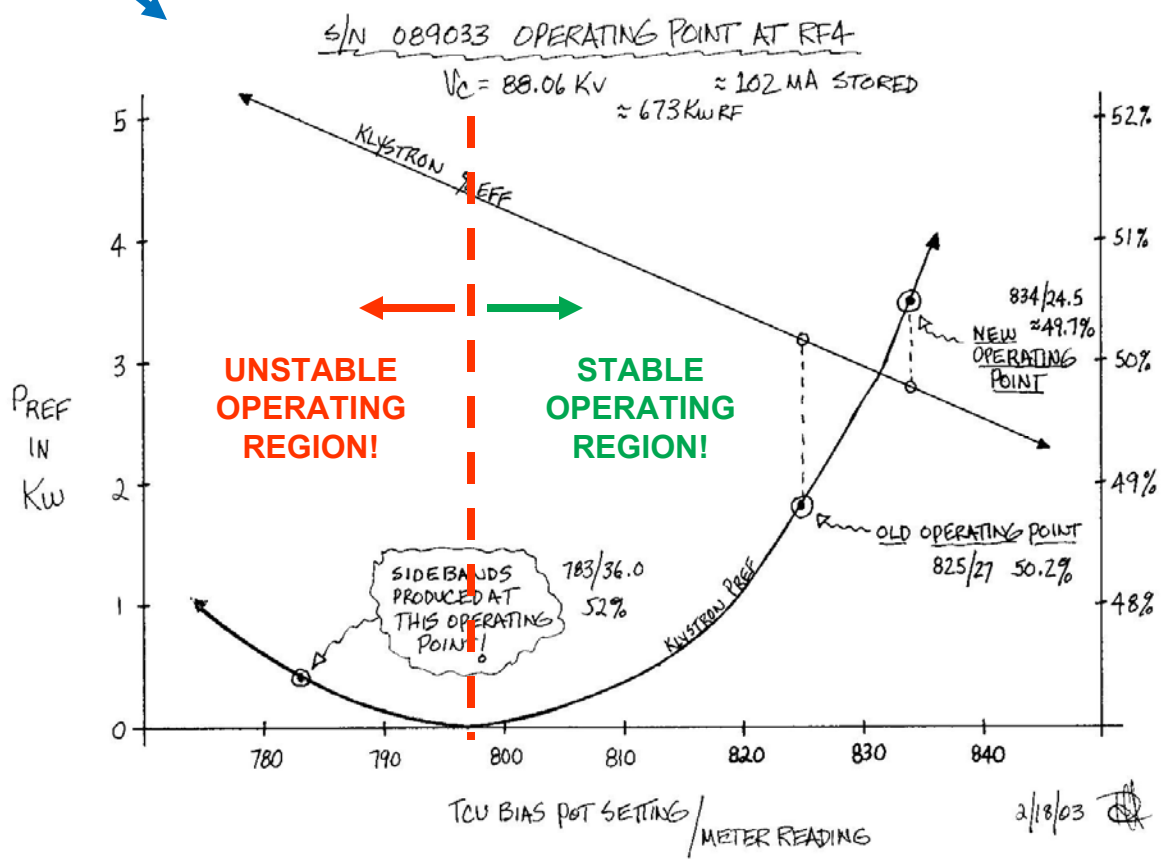
  → **360Hz most likely is ripple from a 3-phase rectifier, <u>most likely the UVC HVPS</u>!**

- Repeated sudden beam losses at the same stored current amount, typically during fills, is a strong indicator of klystron instability sidebands.

Addressing Sideband Issues

- **Klystron sidebands are addressed using various methods:**

1. Confirm that the circulator is tuned on the stable side of the reflected power null



Addressing Sideband Issues

2. **Elevated mod-anode current or current spikes almost always occur when you have backstreaming electrons that create sidebands!**

   → **Monitor mod-anode current and sideband detector output together on a scope triggered by the "beam is lost" signal.**

   Simultaneous increases in mod-anode current and sideband detector analog output just before a beam loss is a very reliable confirmation indicator for sidebands.

3. **Make small adjustments (~ +/- 10%) in klystron rf drive and re-test.**

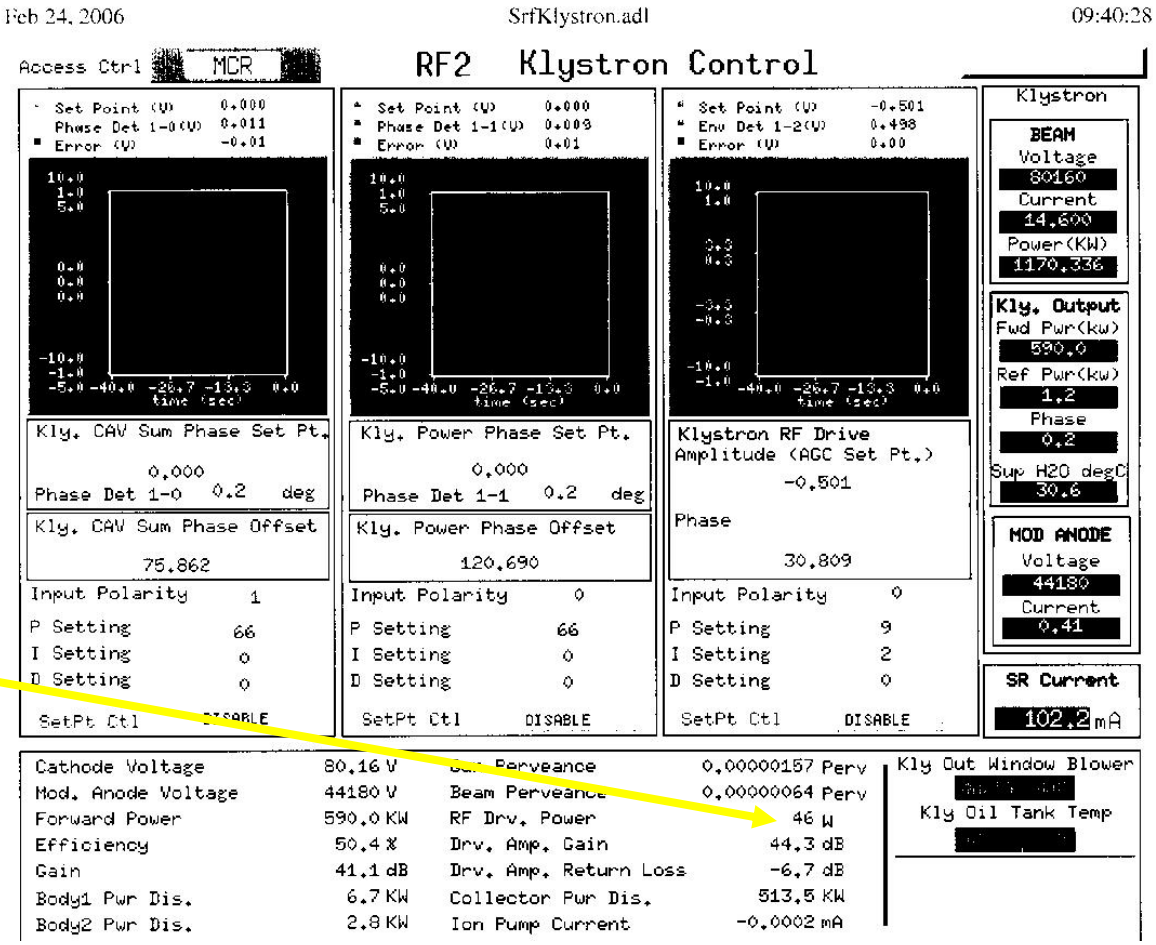
   → **Some klystrons have developed cavity multipactors that are very sensitive to rf drive power and beam current!**

Addressing Sideband Issues

- **The klystron presently in RF2 (Thales s/n 089041) is very sensitive to rf drive power level!**

For years this klystron would remain stable only if the rf drive power was kept within 46-49 watts, and it ran acceptably with 46 watts drive until this May!

Coming out of the May 2009 shutdown, stable operation required 50 watts of drive!



Addressing Sideband Issues

4. Adjust cathode voltage up or down by 1kV and re-test.

→ ***In some cases a 1kV change is all that is necessary to clear the klystron output cavity gap of slowed or stopped electrons that backstream!***

REMEMBER ***– Klystron sidebands can be notoriously difficult to diagnose, and even more difficult to treat. It may require adjustments in several parameters, including klystron cavity tuning to ultimately reach stability!***