RF TECHNICAL NOTE ON EXCESSIVE SIDEBAND LEVEL

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10/31/06

I. Introduction

Any sideband energy on the 352MHz Storage Ring rf power that is within the rf cavity bandwidth can drive the stored beam and result in increased beam motion. In most cases, this sideband energy is a product of incidental amplitude and phase modulation of the rf station output. The dominant source of this modulation is the ac power line, and the modulation can occur in both the low-level and high-level sections of the rf systems. This technical note describes how these unwanted sidebands are created, how to detect and measure them, and how to determine if the sideband level is excessive.

II. Sources of Incidental Amplitude and Phase Modulation

There are several potential sources of incidental phase and amplitude in the 350MHz rf systems. The most common source is the ripple that normally is present on the output of the UVC power supply. Under normal operating conditions, the UVC power supply output will have approximately 900v p-p of T-R set rectifier pulse ripple at 360Hz superimposed on the klystron cathode voltage. This ac ripple component will cause the klystron to produce approximately 7º p-p of rf phase shift. The LLRF power phase and cavity-sum phase loops are designed to eliminate most of this incidental phase modulation, resulting in a peak-to-peak phase jitter of less than 1º. This level of correction, plus the use of ac-coupled negative feedback to cancel incidental amplitude modulation, results in sideband levels down greater than -50dBc under normal conditions, as shown in Figure 1.

These sidebands are a product of both amplitude and phase modulation, but due to the very low modulation indices involved, it is impossible to determine the individual contribution of each type of modulation. However, the non-symmetrical nature of the 360Hz sidebands shown in Figure 1 is a strong indication that they are due primarily to the effects of phase modulation.

Along with normal 360Hz ripple, any cathode or anode voltage regulation problem that would result in either an oscillation or N x 60Hz instability, such as SCR phase imbalance, will also result in increased output ripple at ac-line related frequencies other than the normal 360Hz. There will be a set of sidebands displayed for each ripple frequency component.

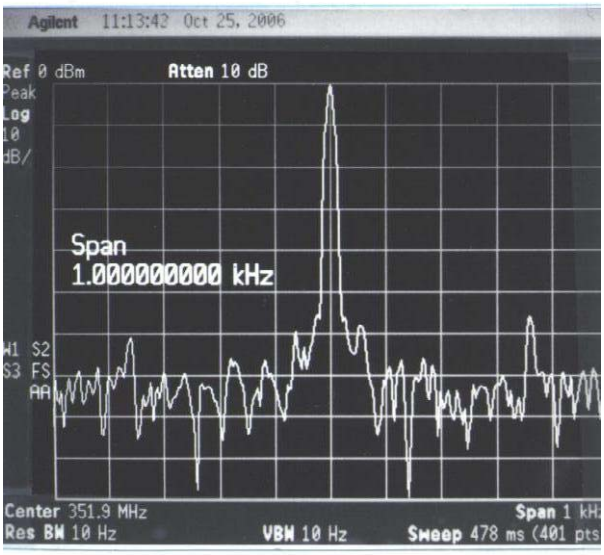

Figure 1 – RF4 klystron output, showing normal N x 60Hz sideband levels. *Note that the dominant sideband is +/- 360Hz from the carrier.*

An example of high sideband levels that did cause excessive beam motion is shown in Figure 2. In this particular case, the source of the sideband energy was actually the main 352MHz rf synthesizer, which was being phase modulated by 120Hz phase noise present on the output of the 10MHz reference oscillator used as a timebase by the synthesizer. The rf stations simply amplified the sidebands present on the noisy rf source signal, as the sidebands were well within the bandwidth of the rf systems.

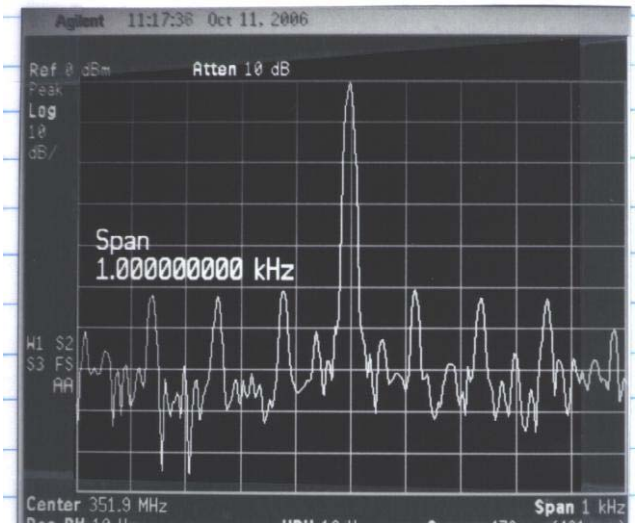

Figure 2 – Excessive sideband noise on the RF4 klystron output. *Note that the sidebands were abnormal and caused excessive beam motion*, *but the sideband levels were still below -50dBc.*

This particular problem was elusive to troubleshoot, as both the main and standby 352MHz synthesizers displayed the same level of excessive sideband noise in their outputs (see Figure 3). Since both synthesizers share the same external 10MHz reference source, the reference oscillator was suspected as the root source of the N x 60Hz noise. However, excessive N x 60Hz sidebands in the 10MHz reference output were not immediately obvious, as shown in Figure 4.

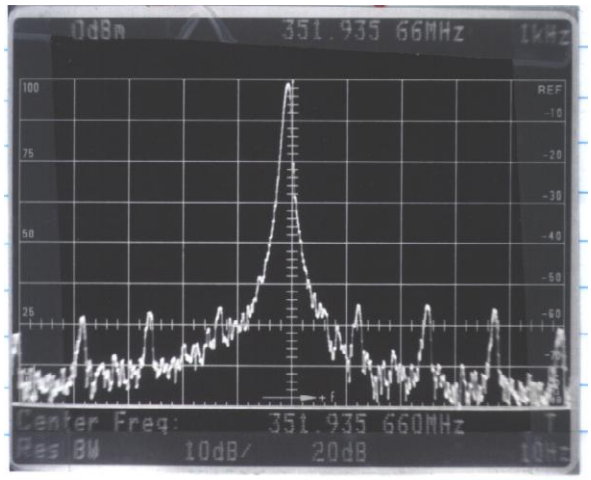

Figure 3 – N x 60Hz sideband noise in output of rf source. *Note: The multiple harmonic sidebands seen in the display are caused by the high harmonic distortion content of the 120Hz ripple waveform.*

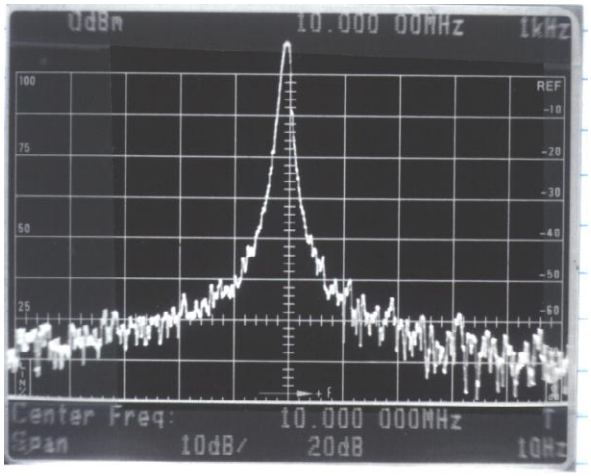

Figure 4 – Defective output of 10MHz reference oscillator.

A third stand-alone synthesizer was used to prove conclusively that the 10MHz reference oscillator was the source of the sideband noise. The problem was further traced to a defective 24Vdc linear power supply in the 10MHz reference oscillator that had developed excessive 120Hz ripple due to dried-out filter capacitors. The power supplies in the 10MHz source were replaced with spares, and everything returned to normal. Figure 5 shows the output of the main 352MHz synthesizer under normal conditions, viewed on a spare rf source output on the source switching chassis. *The output of the synthesizer and all subsequent rf source signals should have no discernable sidebands on either side of the carrier.*

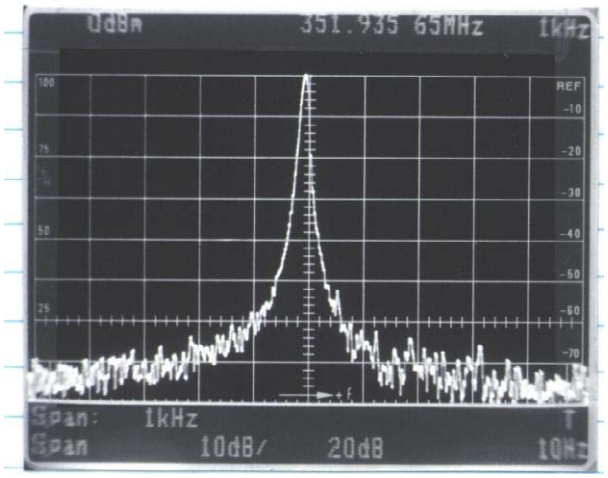

Figure 5 – Normal rf source output.

Other potential sources of sideband noise in the 350MHz rf systems are shown below:

a) Any of the numerous 24Vdc linear power supplies used to power LLRF amplifiers at various points in the rf systems. *These power supplies utilize full-wave rectifiers, so their dominate ripple frequency will be 120Hz.*

b) Any switching power supply, such as the 24Vdc power supplies internal to the Kalmus amplifiers and the LLRF VXI crates. *Defects in these power supplies could cause excessive ripple at frequencies typically between 5-20kHz.*

c) Unlocked power-phase or cavity-sum phase loops.

d) Any instability (oscillation) in a LLRF or HLRF phase or amplitude loop.

Any of these noise sources can result in sideband generation at the fundamental and harmonics of the possible modulation frequencies.

Another condition that can result in sidebands in the output of the klystron is an electron instability internal to the klystron that results in back-streaming electrons traveling from the output cavity to the gun. Sidebands created by this process look very different than those generated by incidental amplitude and phase modulation.

NOTE: Sidebands created by klystron electron instabilities typically are spaced at approximately 2MHz intervals (roughly the klystron cavity #2 resonant frequency) above and below the carrier, and can be quite strong (see Figure 6). Normally, sidebands of this type are well outside of the storage ring cavity bandwidth and therefore can be present without affecting the storage ring beam. However, under certain conditions, these sidebands can randomly move about in frequency close enough to the carrier frequency to fall within the storage ring cavity bandwidth and couple into the beam. This typically results in extreme storage ring beam motion and subsequent beam loss.

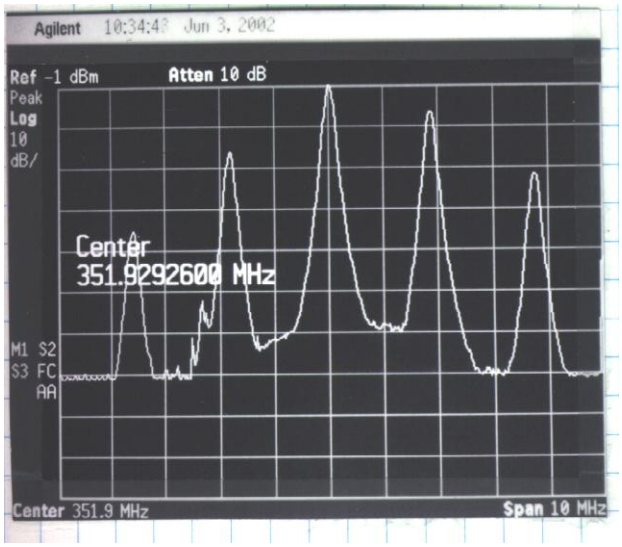

Figure 6 – Klystron-produced sidebands, caused by electron instability in the Thales klystron at RF2 (s/n 089041). *Note the 2MHz spacing between the sidebands.*

III. Measurement of Sideband Levels

Sideband measurements can be made using isolated rf signals available from test points at the rf stations, and at the rf source in A014/rack 9. Which signal you use at each location depends on the nature of the operating problems.

At the rf stations, the first signal to examine is the klystron output. The klystron output signal is normally connected to the rack-mounted spectrum analyzer rf

input at each rf station, and is displayed continuously. If sidebands are seen on the klystron output, then continue to isolate the source of the sidebands by making similar checks on the klystron driver amp output and the rf source. If the driver amp and source signals are clean, then the klystron is generating the sidebands due to a problem in either the LLRF system of the UVC power supply.

If the rf source signal has sidebands, the root problem is likely in the rf source equipment in A104 (racks 7 and 9). Sideband noise on the rf source signal will be amplified by all of the storage ring rf stations, resulting in high sideband levels at all the stations.

A spectrum analyzer capable of 10Hz resolution bandwidth is required to view and measure N x 60Hz ac power line sidebands. At this time, the Agilent units mounted at each rf station have this capability, along with the roll-around Tektronix analyzer normally stored in the 420 test equipment cage. *NOTE: The Tektronix unit is an analog spectrum analyzer, and it needs approximately 20 minutes of warm-up time to stabilize before it can be used to view signals within very narrow spans.*