325 MHz / 1.3 GHz Frequency Converter Module for Vertical Cavity Test Stand

Bob Webber
10/26/2007

Introduction

Plans are being developed to test 325 MHz superconducting spoke cavities in the Fermilab ILC Vertical Test Stand (VTS) in Industrial Building #1. It is prudent to fit the 325 MHz activity into the normal VTS 1.3 GHz operations as seamlessly as possible to take advantage of the existing VTS control system test and data acquisition applications. This can be accomplished through an electrical interface that converts just four RF signals between the two frequencies. This note describes the 325/1300 MHz frequency converter module designed for that purpose.

Signals

The four RF signals that must be interfaced between the 1.3 GHz operating frequency of the existing VTS system and the 325 MHz resonant frequency of the spoke cavities are:

- Low level RF drive signal to the amplifier powering the cavity
- Cavity incident power signal (forward power)
- Cavity reflected power signal (reverse power)
- Cavity transmitted power signal (cavity field probe)

The RF drive signal must be down-converted from 1.3 GHz to 325 MHz; the other three signals must be up-converted from 325 MHz to 1.3 GHz.

The VTS LLRF System and Signal Levels

The VTS low level RF and data acquisition system is described in “Functional Description of the ILCTA-IB1 Cavity Test Stand RF, Control, and DAQ System” by J. Ozelis (Fermilab) and T. Powers (TJNAF) dated June 5, 2007. The RF circuits for this VTS system offer “a few hundred MHz bandwidth” for locking to the resonant frequency of the cavity under test; this is more than adequate to cover the expected (<25 MHz) range of uncontrolled variability in the resonant frequency of the 325 MHz cavities.

The schematic of the VTS “Transmitted Power/PLL Module, VCO_RF Drive, and Power Measurement Module” specifies design power levels for the relevant signals. The VTS 1.3 GHz low level RF drive signal output typically operates in the range of 0 to +5 dbm with a maximum level of +10 dbm. The incident and reflected power signal receivers of the VTS system expect signals between -13 and +27 dbm. The cavity transmitted power signal receiver is set to accept signals between -30 and +30 dbm or between -20 and +40 dbm depending on the presence of a 10 db attenuator. The 325/1300 MHz frequency converter signal channels are designed to offer compatibility with these levels.

The Frequency Converter Module Requirements and Design

The frequency converter module must accept the 1.3 GHz RF drive signal from the VTS system, down-convert that signal to 325 MHz, and provide an output signal level compliance that is compatible with an external RF power amplifier to generate the required cavity drive power. This down-converter channel is required to provide amplitude linearity with loose tolerances and stable phase transmission. Requirements on harmonics and spurious frequency products are relatively relaxed, as these will be attenuated by the limited bandwidth of the RF power amplifier and strongly rejected by the narrow bandwidth of the cavity under test.

The three up-converter channels must receive the 325 MHz incident and reflected power signals from a directional coupler in the cavity drive line and the 325 MHz transmitted power signal from a pick-up probe in the cavity. It must up-convert these signals to 1.3 GHz and deliver output levels compatible with the respective VTS 1.3 GHz receiver channels. Amplitude linearity of all three channels is critical to the accuracy of the cavity measurements to be made and phase stability of the transmitted power signal is important for locking the system to the cavity resonant frequency. Harmonics and spurious products generated by the up-converter channels ultimately limit the dynamic range of the overall system.

The frequency converter module is housed in a 5 ¼" high, 19" rack mount chassis. It requires 120 VAC single phase power for an internal local oscillator and for RF amplifiers. All RF inputs and outputs are via type N connectors on the rear panel.

A single 975 MHz local oscillator signal is common to all four converter channels. Accommodation is made for the local oscillator reference signal to be provided either by an external frequency generator (+2 dbm input level) or by a Wenzel crystal oscillator with frequency multiplier internal to the frequency converter chassis. Phase noise of the converted signals is directly determined by the performance of the local oscillator source.

Apart from the local oscillator, the frequency converter module is designed around "off-the-shelf" RF components in connectorized packages, primarily from the MiniCircuits product line because of ready availability and well-characterized performance. Level 17 mixers are employed due to the generally high signal levels presented to and expected from the converter channels.

RF inputs to the one down-converter and three up-converter channels are nominally 50 ohm impedance and are isolated from the frequency mixer inputs with 3 db attenuators. The mixers are each followed by another 3 db attenuator for isolation, filters for rejection of harmonics and spurious products, and finally amplifiers to establish the desired output power levels. All RF outputs are designed for 50 ohm impedance loads.

Appendix 1 contains a schematic diagram of the frequency converter circuitry.

Parameter	1300 to 325 MHz Down-converter Channel	325 to 1300 MHz Up-converter Channels
Maximum operating input	+10 dbm	+10 dbm
Nominal channel gain	+5 db	+9 db
Amplitude non-linearity	<2% for -5 to +10 dbm input	<2% for -20 to +10 dbm input
Bandwidth	~100 MHz	~100 MHz
Dominant harmonic/spur (10 dbm in)	650 MHz >32 db below 325	1.625 GHz >40 db below 1.3GHz
Dominant harmonic/spur (<0 dbm in)	650 MHz >45 db below 325	975 MHz at constant -30 dbm
Output amplifier capability	15 dbm @ 1 db comp.	24 dbm @ 1 db comp.

Table 1. Converter performance specifications summary.

Performance

Table 1 summarizes operational parameters for the frequency converter channels. Appendix 2 contains plots of typical output spectra and measured harmonics and spurs as a function of input amplitude and linearity (gain constancy) for each converter channel.

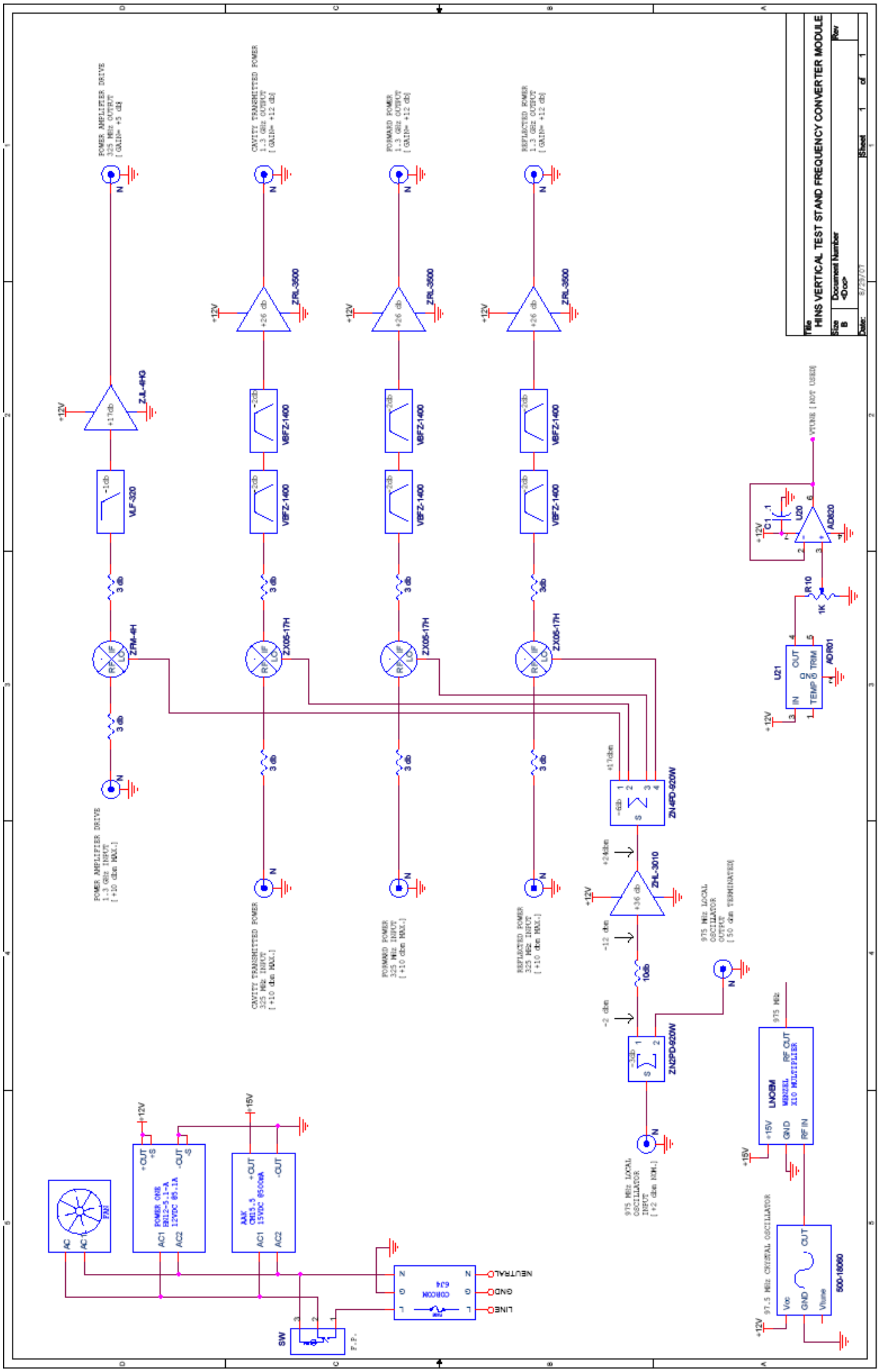
The residual output spectral component that is most likely to limit the useful dynamic range of the frequency converter module in the VTS application is the local oscillator (LO) feedthrough in the up-converter channels. This 975 MHz signal is present at the up-converter output at a level of approximately -30 dbm, independent of the channel input. With a nominal up-converter channel gain of 9 db, the LO feedthrough power will be of equal strength to the desired 1.3 GHz signal at the converter output for a 325 MHz input signal of -39 dbm. Alternatively, a 1% power error will be experienced at the up-converter output for a -19 dbm 325 MHz input signal due to the undesired LO feedthrough signal. The up-converter channels therefore offer a 29 db (~ amplitude factor of 30) dynamic range (-19 to +10 dbm input) with power errors at the level of 1% or better. This range can be extended if system calibrations are done to compensate for the -30 dbm power offset. Improved filtering downstream of the up-converter mixers is also a option should current performance prove unsatisfactory.

Summary

A four-channel frequency converter has been constructed to interface the 1.3 GHz ILC VTS system to 325 MHz cavities. One down-convert channel provides about 5 db gain and better than 2% linearity for 1.3 GHz inputs up to +10 dbm. Harmonics and spurious frequency products are all down from the desired 325 MHz output by 32 db at the 10 dbm input level and drop faster than linearly as the input level is reduced. Three up-convert channels provide about 9 db gain and better than 2% linearity for 325 MHz inputs up to +10 dbm. Harmonics and spurious frequency products are all down from the desired 325 MHz output by 40 db at the 10 dbm input level. A 975 MHz component, due to local oscillator feedthrough, is present at the down-converter outputs at a level of about -30 dbm, independent of down-converter input. This has the potential to define the low end of the useful dynamic range of the down-converter channels.

Appendix 1

Frequency converter module schematic diagram.



Appendix 2

This appendix contains plots of the output spectrum for the 1.3 GHz to 325 MHz down-converter channel (Fig. 1) and for a typical one of the three up-converter channels (Fig. 2). Figures 3-10 show the measured harmonics and spurs as a function of input amplitude and the linearity (gain constancy) for the up-converter channel and for each down-converter channel.

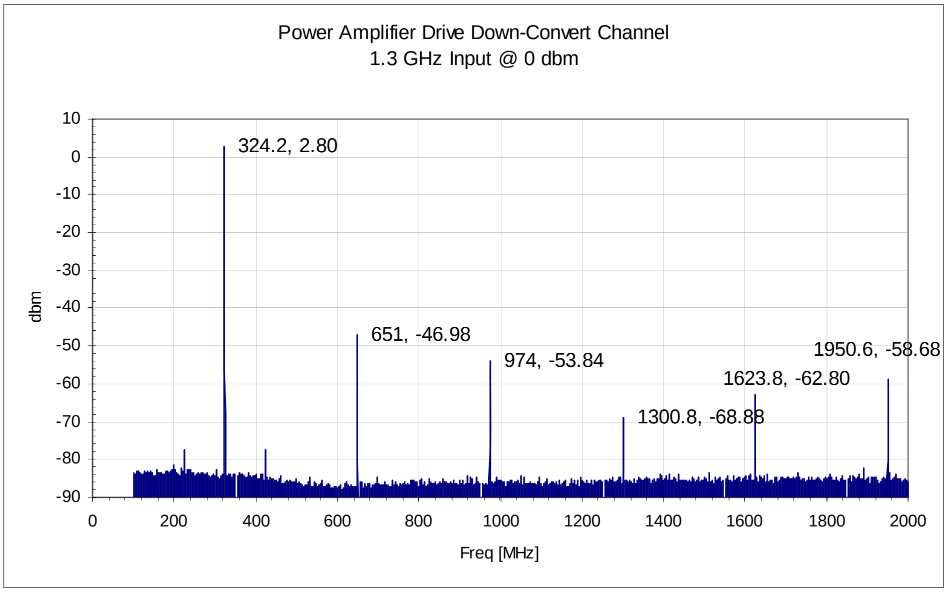


Figure 1. Down-convert channel output spectrum for 0 dbm 1.3 GHz input.

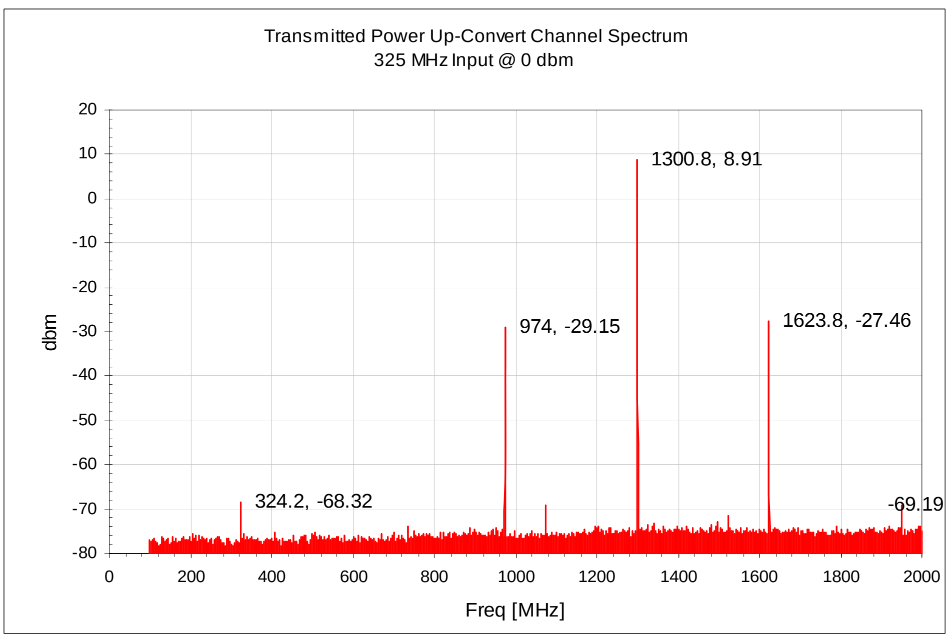


Figure 2. Typical up-convert channel output spectrum for 0 dbm 325 MHz input.

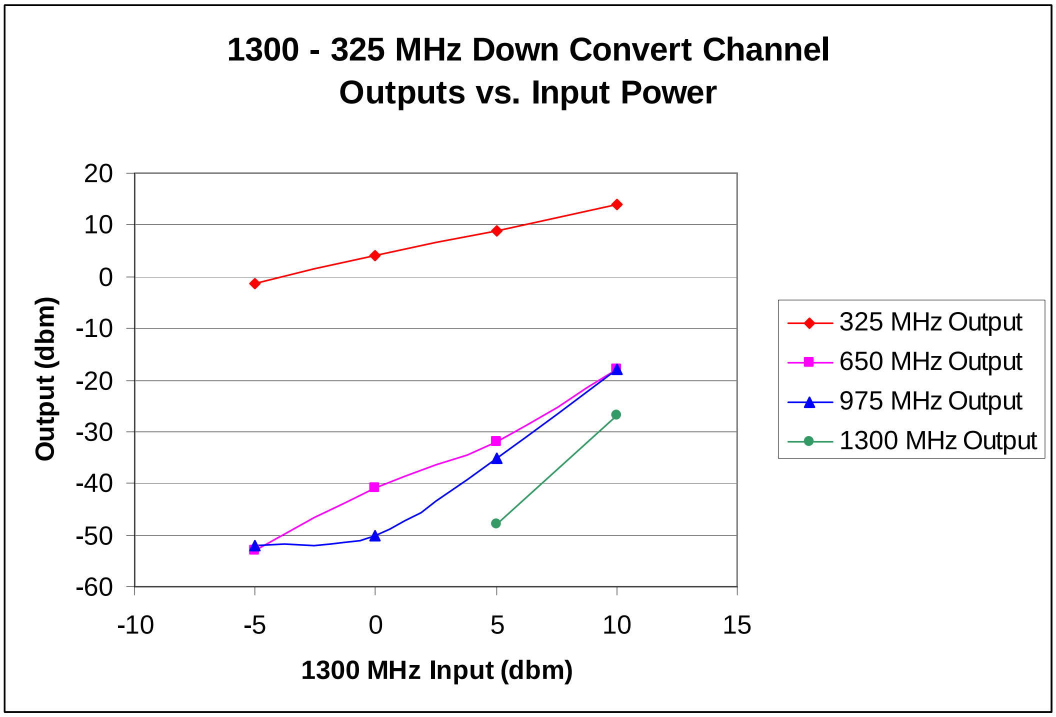


Figure 3. RF Drive down-convert channel harmonics and spurs.

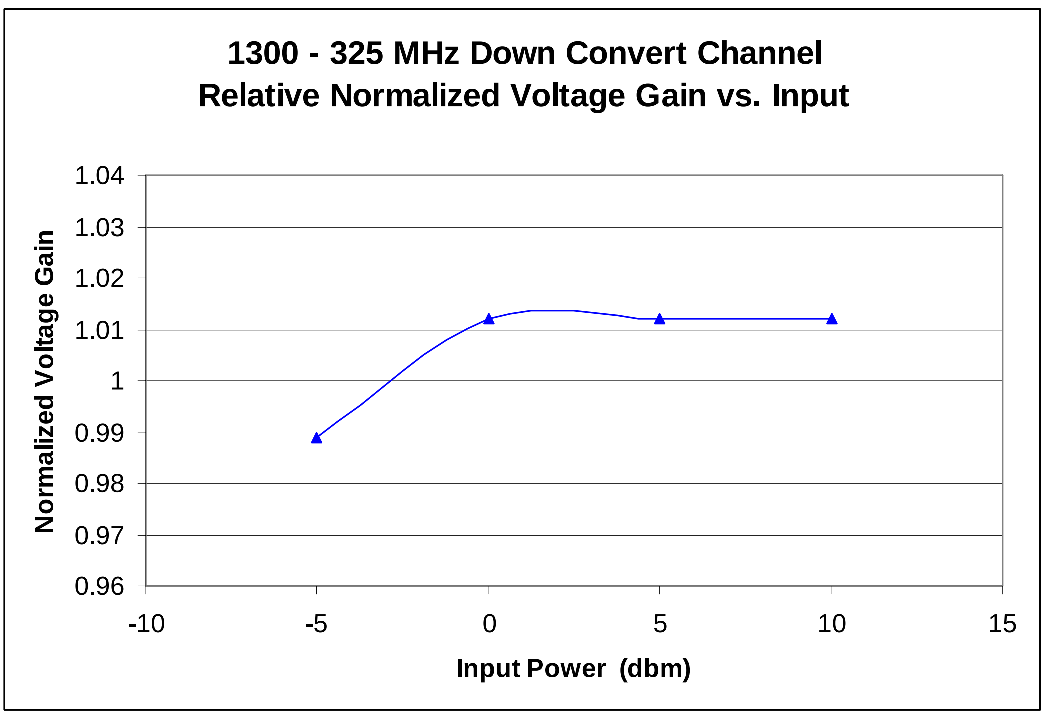


Figure 4. RF Drive down-convert channel linearity normalized to 3.9 db gain.

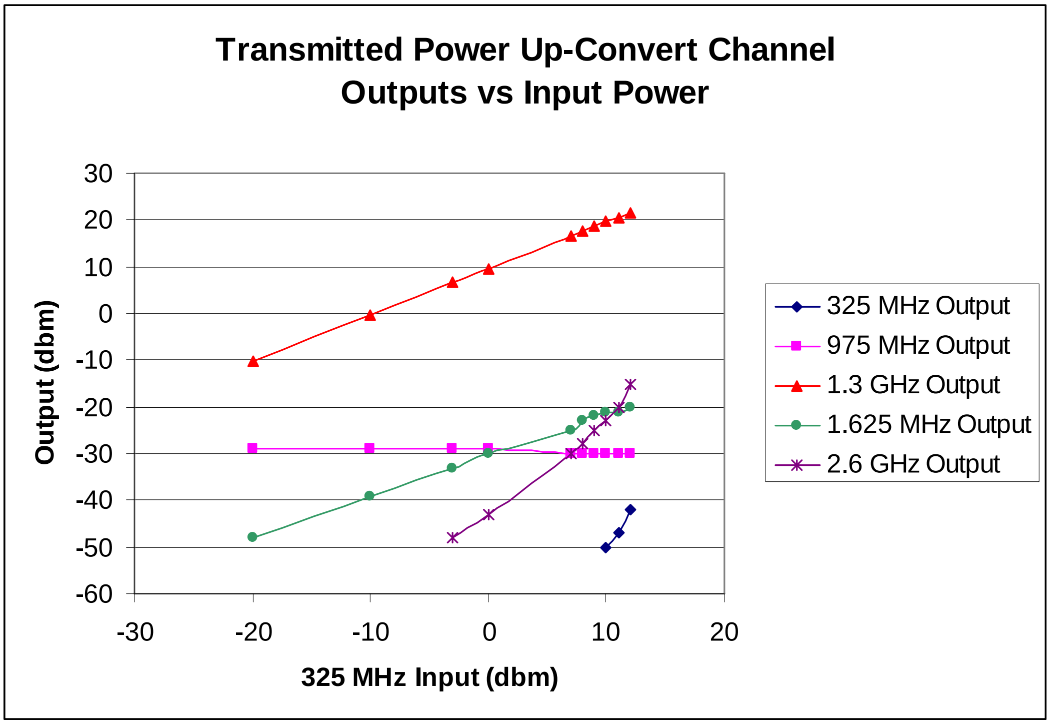


Figure 5. Transmitted Power up-convert channel harmonics and spurs.

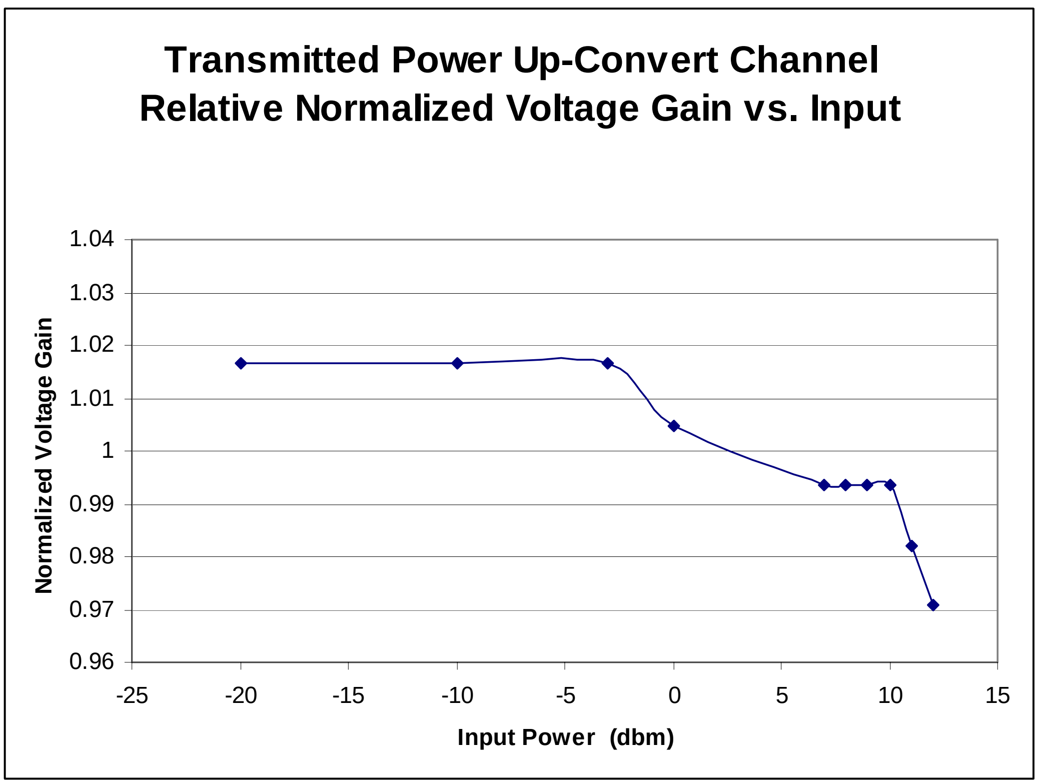


Figure 6. Transmitted Power up-convert channel linearity normalized to 9.7 db gain.

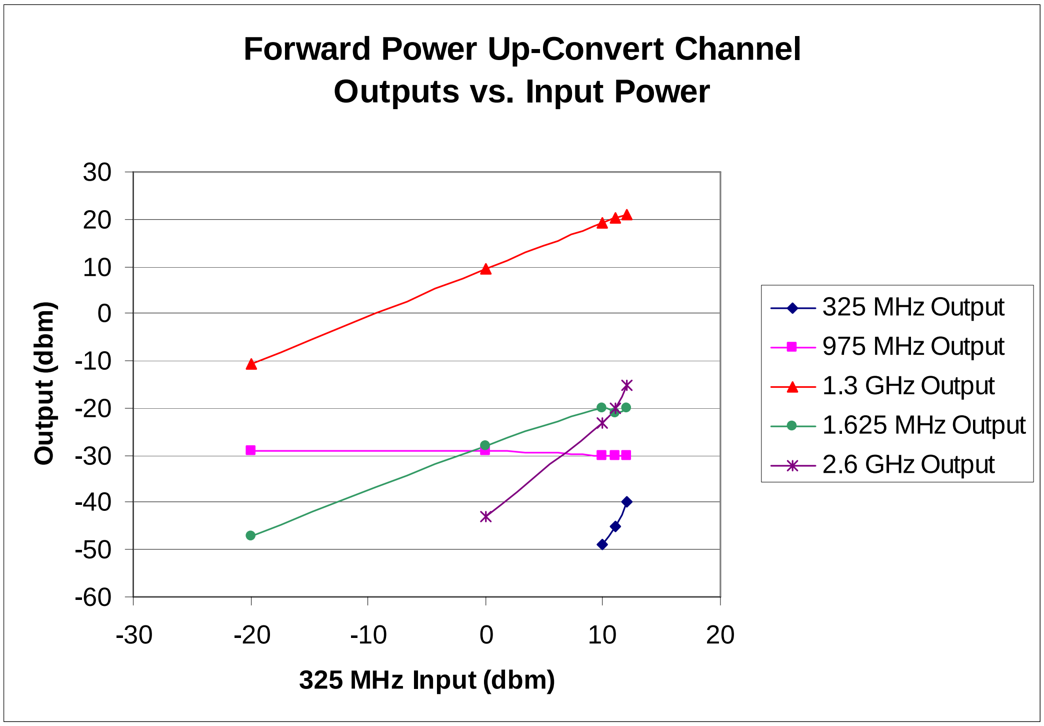


Figure 7. Forward Power up-convert channel harmonics and spurs.

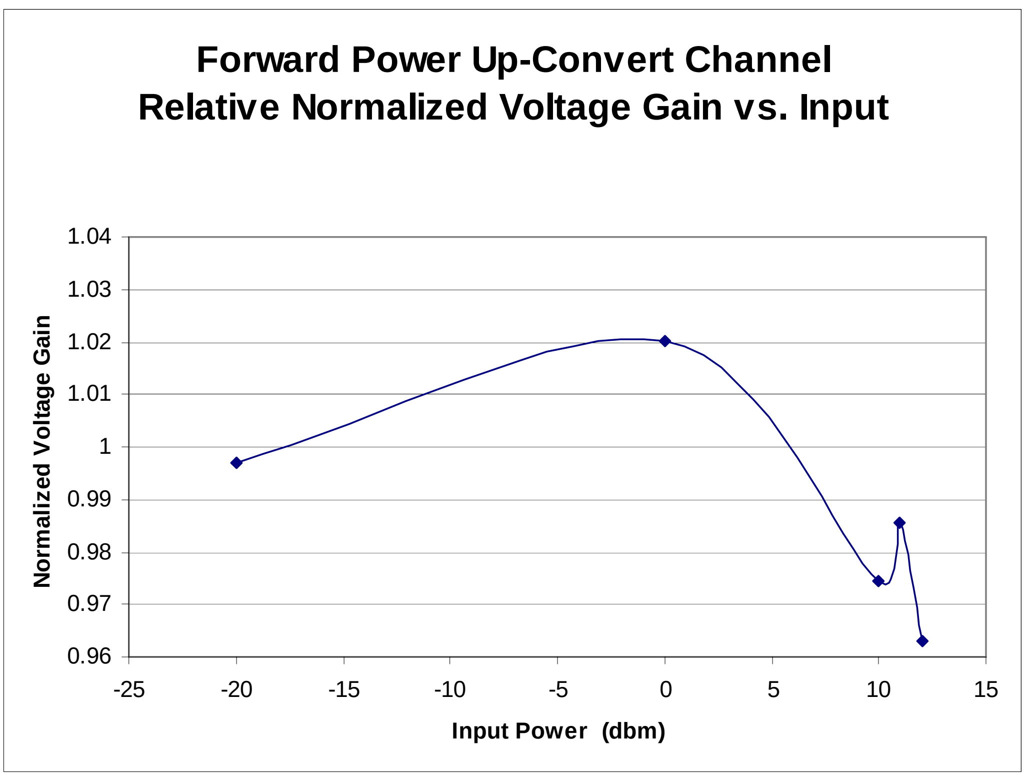


Figure 8. Forward Power up-convert channel linearity normalized to 9.4 db gain.

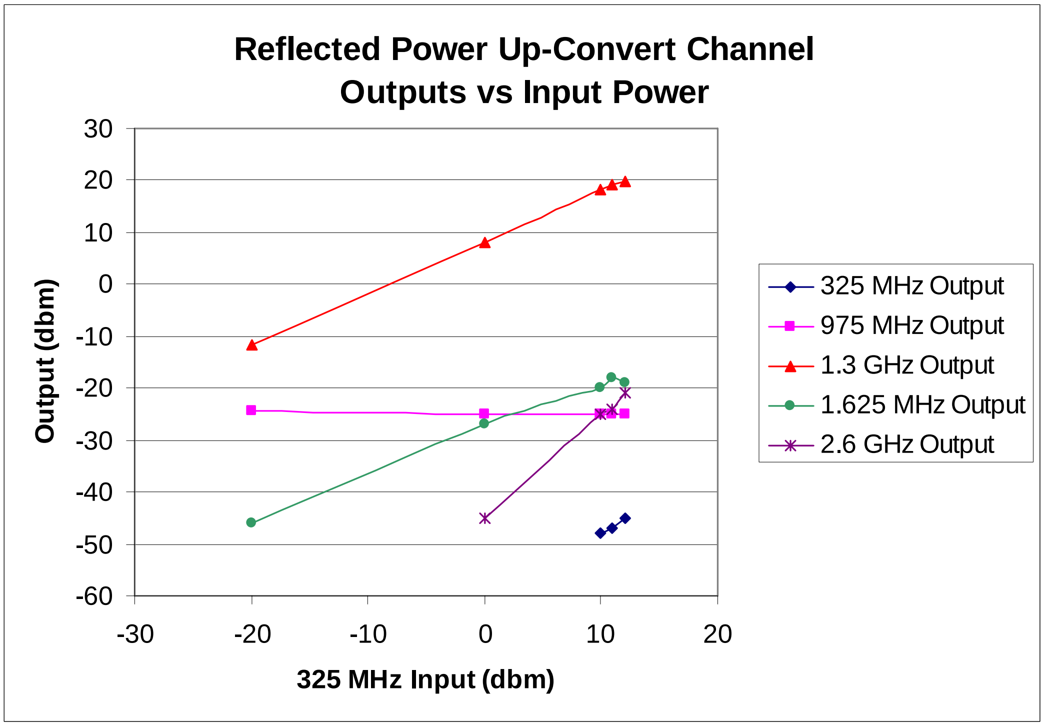


Figure 9. Reflected Power up-convert channel harmonics and spurs.

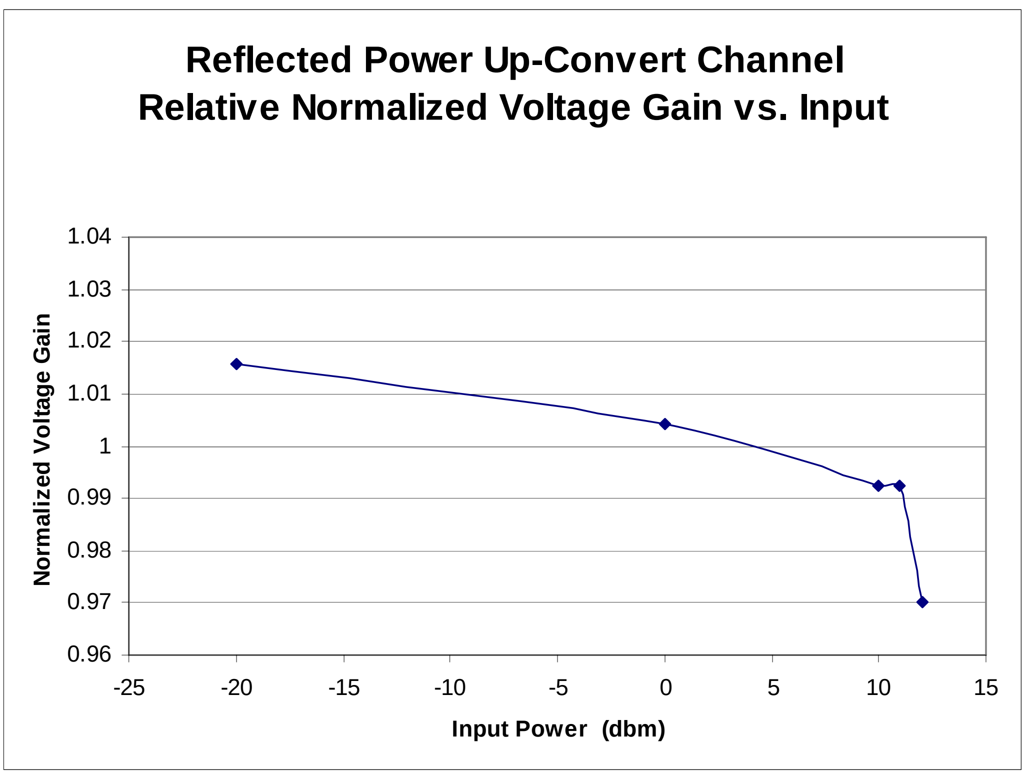


Figure 10. Reflected Power up-convert channel linearity normalized to 8.2 db gain.