

Third-Order Intermodulation Reduction by Harmonic Injection in a TWT Amplifier

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Abstract—A method for reducing the two-tone third-order intermodulation products arising from two carrier frequencies at 1.95 and 2.00 GHz is demonstrated in a travelling wave tube distributed amplifier. The optimum amplitude and phase of an injected second harmonic and the resulting intermodulation suppression, of upto 24.2dB, are examined for fundamental drive levels approaching saturation.

Index terms—harmonic injection, traveling wave tube, IM3, nonlinear distortion

I. INTRODUCTION

When multiple carrier frequencies are amplified in a traveling wave tube (TWT) or other non-linear amplifier, various order intermodulation products (IMPs) arise from the sum and difference of these frequencies. Certain IMPs are of concern since they lie close to the fundamental tones being amplified, thereby limiting the useful bandwidth of the amplifier. For example, in a simple excitation of f_1 and f_2 , the two-tone third-order intermodulation products (IM3s) arise from $2f_1 - f_2$ and $2f_2 - f_1$, whereas IM5s with nearby frequencies arise from $3f_1 - 2f_2$ and $3f_2 - 2f_1$. The work described here injects an additional signal into a TWT at the frequency of the second harmonic of the upper fundamental drive tone (f_2). When this injected signal at $2f_2$ is of the proper phase and amplitude, a significant reduction in the upper IM3 ($2f_2 - f_1$) is observed.

This is the first experimental examination of IM3 reduction using the harmonic injection technique in a TWT distributed amplifier. A recent study by Aitchison *et al.* [1] has demonstrated the effectiveness of this technique in narrowband, solid-state amplifiers at 835 and 880 MHz. They obtain substantial reduction in IM3 levels by both second harmonic and difference-frequency (1 MHz) injection techniques. Work by Datta *et al.* [2] and Wohlbiel [3] describe theoretical models that predict similar behavior in TWTs. This behavior has been observed [4] but not published nor studied in detail. Additionally, the sensitivity of IM3 reduction to the injected harmonic's amplitude and phase is also explored.

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II. EXPERIMENTAL DEVICE AND SETUP

A. Description of XWING TWT

The TWT used in this investigation, termed the XWING TWT (for eXperimental WIsconsin Northrop Grumman TWT), is a research version of a product manufactured by Northrop Grumman. This two-stage, helical TWT provides a moderate gain of 20-30 dB over a frequency range of 2-6 GHz. In the following experiments, fundamental tone output levels are in the range of 33-37 dBm.

B. Experimental Setup

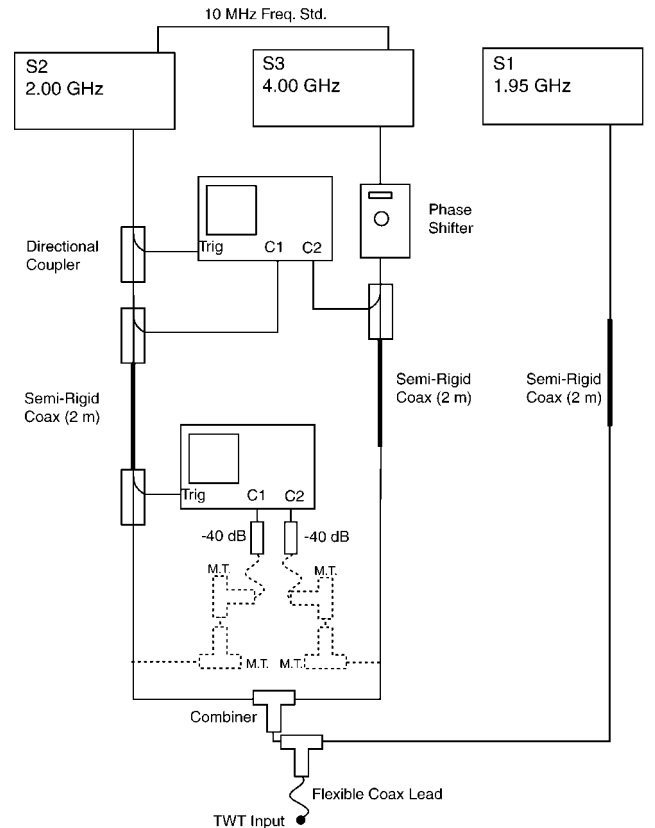


Fig. 1. Block diagram of single-harmonic injection experimental setup. Dashed lines show connections that were made with the TWT deactivated. Matched terminations (M.T.) were placed on open combiner ports.

To maintain precise frequency and phase relationships, three frequency synthesizers were used to supply the two fundamental tones and the harmonic. Since the phase of the

injected harmonic must be referenced with respect to the higher frequency fundamental, two Agilent 83623B synthesizers were configured to share a common 10 MHz phase reference signal.

The upper fundamental and harmonic frequencies were set to 2.00 and 4.00 GHz, respectively. The 4.00 GHz signal was sent through a Narda 3752 phase shifter, allowing the fundamental-to-second harmonic phase relationship to be adjusted in real-time. The lower fundamental frequency of 1.95 GHz was supplied by a Wavetek 3520 synthesizer, providing a 50 MHz difference between the two drive tones. The phase of this fundamental was not referenced to any other signal.

The phase relationship between the upper fundamental and the injected harmonic was monitored on two Agilent 86100A wide-bandwidth oscilloscopes. A schematic of the TWT input network is shown in Fig. 1.

III. EXPERIMENTAL PROCEDURES AND RESULTS

A. 15 dBm/tone Fundamental Drive Levels

First, the 1.95 and 2.00 GHz fundamental drive tones were independently set to 15 dBm/tone at the TWT input tap, and the output spectrum was captured on an Agilent E4407B digital spectrum analyzer. This TWT output spectrum is shown in Fig. 2a. Next, the 4.00 GHz second harmonic tone was injected at the TWT input and the phase was varied, with respect to the 2.00 GHz fundamental, to achieve the lowest IM3 level.

With the phase relationship optimized, the injected harmonic amplitude was varied until a maximum suppression in the upper IM3 level was observed. This occurred with an injected harmonic amplitude of -2.1 dBm or 17.1 dB below f_2 . The optimized TWT output spectrum is shown in Fig. 2b. Notice that the upper IM3 is reduced by 21.3 dB, yielding an upper carrier to IM3 power ratio of 43.9 dB. The sensitivity of the IM3 level to variations in the injected harmonic amplitude and phase is shown in Fig. 3. In all cases, the IM3 power was measured to within an accuracy of 0.2 dBm.

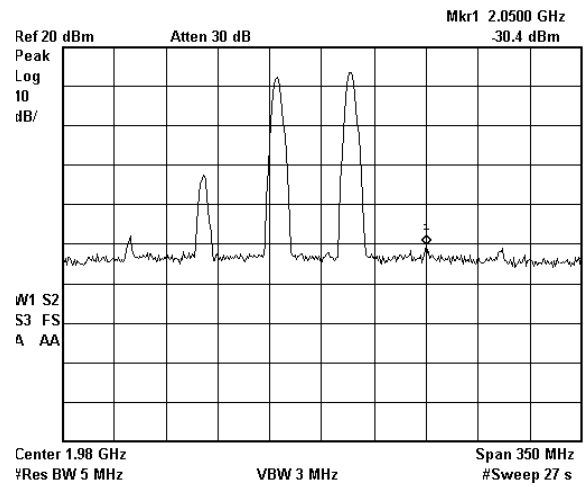
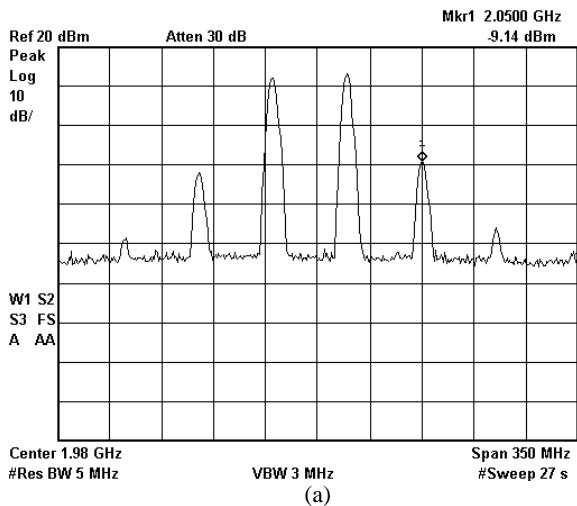


Fig. 2. TWT output spectrum for two-tone, 15 dBm/tone input: (a) without and (b) with harmonic injection technique showing 21.3 dB reduction in upper IM3 level.

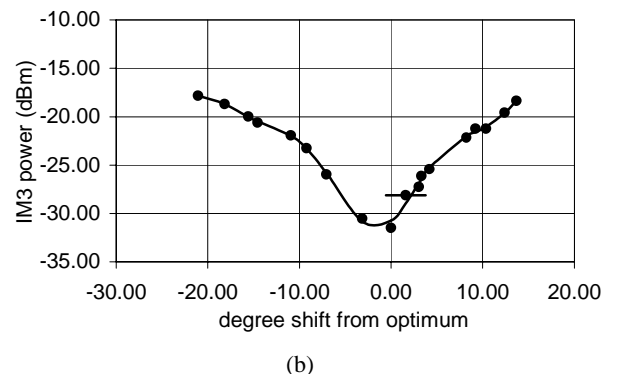
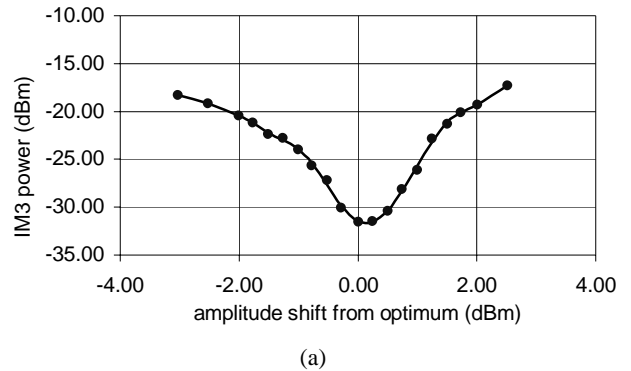


Fig. 3. Sensitivity of IM3 suppression to: (a) variation in injected harmonic amplitude and (b) variation in injected harmonic phase, with respect to 2 GHz fundamental.

B. 18 dBm/tone Fundamental Drive Levels

The experiment was repeated at higher input drive levels of 18 dBm/tone. The upper and lower fundamental tones were amplified by separate solid-state amplifiers (DBS DB94-0373 and Mini-Circuits ZHL-42W). Pre-amplifier harmonic content was verified at 30 dB below the carrier. Similar procedures were followed to determine the optimum phase and amplitude for the injected harmonic.

For the optimum case, an IM3 reduction of 24.2 dB was observed, corresponding to an injected harmonic drive level of 0.9 dBm, or 17.1 dB below f_2 . The IM3 suppression is greater than in the previous case, since the TWT is operating closer to saturation and nonlinear distortions are more pronounced. Consistent with the previous case, the improved upper carrier to IM3 power ratio is 43.6 dB. The optimum phase relationship between the injected harmonic and upper fundamental was measured at the TWT input tap. The 4 GHz injected harmonic was found to lead the 2 GHz fundamental by 47.5 degrees, with respect to the 2 GHz fundamental period.

IV. CONCLUSIONS

For two-tone excitation of a distributed TWT amplifier operating near 2 GHz with a 50 MHz separation, a significant reduction in the amplitude of the third-order intermodulation product was achieved by injecting at the second harmonic of one of the drive tones with an optimum amplitude and phase. Reductions of third-order intermodulation products of 21.3 and 24.2 dB were observed for two-tone fundamental drive levels of 15 and 18 dBm/tone, respectively. While this experiment focused on the reduction of the upper third-order intermodulation product, both may be reduced by adding another tone with the appropriate amplitude and phase at twice the lower fundamental frequency.

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