A MICROWAVE LINEARITY TEST SET

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Abstract

A multitone intermodulation (IM) test set has been constructed which generates up to three VHF test tones with conventional accuracy (10^{-3}) and stability ($<10^{-4}$). Using a phase locked microwave generator as local oscillator source, these tones are up-converted, filtered and amplified individually to maintain spectral purity of the microwave test tones. High mutual isolation is provided in the combining circuitry. The detector circuit for signal and IM product tones uses selective tone attenuation to improve its linearity to $M_{\alpha+\beta-\gamma} <-113$ dB. Tone levels are measured to -110 dBm with >80 dB discrimination outside a 20 kHz bandwidth, using a narrow band (1.7 kHz) tunable VHF receiver.

Introduction

Evaluation of the linearity performance of microwave devices forms an increasingly important part of device characterization for many applications, such as communication systems, where nonlinearities give rise to intermodulation (IM) noise. A number of characterization techniques are presently used[1] including single tone ("1 dB gain compression point"), multitone ("intercept point" or "IM coefficient") and white noise ("noise-power-ratio, NPR") excitation.

This paper discusses the design and operation of a multitone test set with three tones (frequencies designated: α, β, γ) implemented. The set measures the amplitude of any signal output tone (e.g. P_β [dBm]) or IM product tone (e.g. $P_{\alpha+\beta-\gamma}$ [dBm]) from the device under test over a wide dynamic range and with convenient frequency agility. The readings are entered into a desk-type calculator which evaluates and plots the corresponding IM coefficients,[1] such as:

$$M_{\alpha+\beta-\gamma} = P_{\alpha+\beta-\gamma} - (P_\alpha + P_\beta + P_\gamma) \text{ [dB]} \quad (1)$$

or

$$M_{2\alpha-2\beta+\gamma} = P_{2\alpha-2\beta+\gamma} - (2P_\alpha + 2P_\beta + P_\gamma) \text{ [dB]} \quad (2)$$

for typical third and fifth order products.

Test Set Design

The test tone generation circuit (Figure 1) is designed to provide VHF and microwave frequency agility with minimum IM noise and sufficient stability for the narrow band detector circuit. Conventional VHF sources with long term stability of $<10^{-4}$ and a microwave signal generator, stabilized with a phase locked loop to $<10^{-7}$, feed individual up-converters. The unwanted sideband and residual local oscillator outputs from these balanced mixers are suppressed using voltage tunable YIG filters. The desired tones are then amplified individually to avoid intermodulation. Automatic level control (ALC) circuits provide manually adjustable, levelled tone amplitudes to the summing circuit which combines the tones with high mutual isolation. Sampling ports monitor spectral purity on a spectrum analyzer (Figure 2a) and tone levels on a power meter during initial setup. A calibrated, accurately resettable, variable attenuator with negligible IM distortion is used to set the input power level to the device under test.

The detector circuit measures the signal and IM tone levels in the output spectrum (Figure 2b) from the device under test. In this circuit, the conventionally used spectrum analyzer is replaced by a selective tone suppression circuit, a down-converter and a narrow band, tunable VHF receiver.

The IM performance of the detector circuit is limited by the down-converter, but can be improved by selectively attenuating one or more signal tones: two tunable, high Q (TE011 mode) cavities suppress two tones (e.g. α and γ, Figure 3) by >45 dB each. This reduces the detector contribution to the IM output by the sum of all tone suppressions (in dB), resulting, from (1) and (2) in an improvement of the detector of $\Delta M_{\alpha+\beta-\gamma} >90$ dB and $\Delta M_{2\alpha+2\beta-\gamma} >135$ dB. Compared to other IM improvement techniques, such as bridge type tone cancellation, this type has the advantage of retaining the improvement independent of changes in the electrical length or gain of the device under test, makes all of the tone power available for device testing and is more convenient to operate. The passband shaping introduced by these filters is entered into the calculator as part of the initial calibration procedure. Frequency dependent measurements can be made to within ± 1.5 MHz of the filtered tones by varying the β-tone across the band. After down-conversion, tone levels are measured sequentially using the calibrated VHF receiver.

Test Set Performance

As presently implemented, the test set (Figure 4) generates the three VHF test tones variable between 30 MHz and 100 MHz; the variable local oscillator converts these to the microwave test tones between 3.7 GHz and 6.5 GHz, with spacings selected at VHF. The sideband selection filters suppress spurious tones >50 dB below the test tones, which are held to ± 0.05 dB over any 30 MHz band and to ± 0.02 dB over a 4 hour period by the ALC loops. Maximum tone levels of + 20 dBm/tone with $M_{\alpha+\beta-\gamma}$ <-135 dB are avalable for testing.

The lowest detectable tone power level is -110 dBm, limited by the (~ 9 dB) insertion loss (including conversion loss) of the detector circuit and -116 dBm noise floor of the VHF receiver which provides discrimination >80 dB outside a 20 KHz bandwidth. Without selective tone attenuation the effective IM coefficient at the detector input is $M_{\alpha+\beta-\gamma}$ = -33 dB (0 dB attenuator setting); with two tones suppressed $M_{\alpha+\beta-\gamma}$ = - 123 dB. Note that the output attenuator contributes an additional 2 dB/dB improvement in detector linearity.

A typical measurement may involve a 6GHz traveling-wave tube (TWT) where readings of the β signal tone and the $\alpha+\beta-\gamma$ and $2\alpha - 2\beta + \gamma$ IM tones are taken from the receiver in 1 dB increments over a 35 dB range. These dBm readings are entered into the calculator which contains all appropriate calibration factors. The calculator prints each set of data and results and stores the results of a complete run. At the completion of a run, the desired coordinate scales are entered and gain, third-and fifth order IM coefficients are plotted as a function of the selected abscissa (e.g. $P_{out/tone}$ [dBm], Figure 5). If desired, labelled parametric plots can be obtained with the existing program.

Conclusions

A multitone linearity test set has been designed which is capable of generating up to three test tones of presettable relative levels, to a maximum of +20 dBm/tone. VHF frequencies of 30 MHz to 100 MHz with rf test frequencies between 3.7 GHz and 6.5 GHz are available. The detector circuit uses selective tone attenuation to improve detector linearity to $M_{\alpha+\beta-\gamma}$ <-123 dB. Individual IM product output levels of arbitrary order can be measured to -110 dBm with >80 dB discrimination outside a 20 kHz bandwidth. Absolute power levels and third order IM coefficients can be measured to ±0.2 dB and ±0.6 dB, relative changes to ±0.05 dB and ±0.1 dB, respectively, over a 40 dB dynamic range. This range can be increased to 140 dB with reduced accuracies.

Reference

1. See e.g.: G. L. Heiter, "Characterization of Nonlinearities in Microwave Devices and Systems", IEEE Trans. MTT, 21, 12, Dec. 1973; pp 797-805.

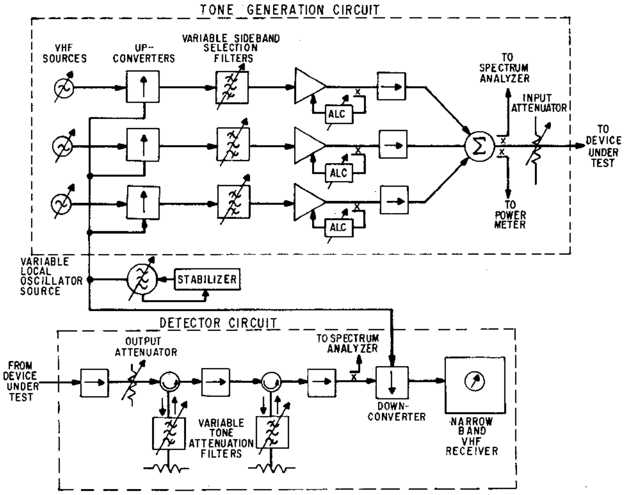

Fig. 1-Schematic Intermodulation Test Setup

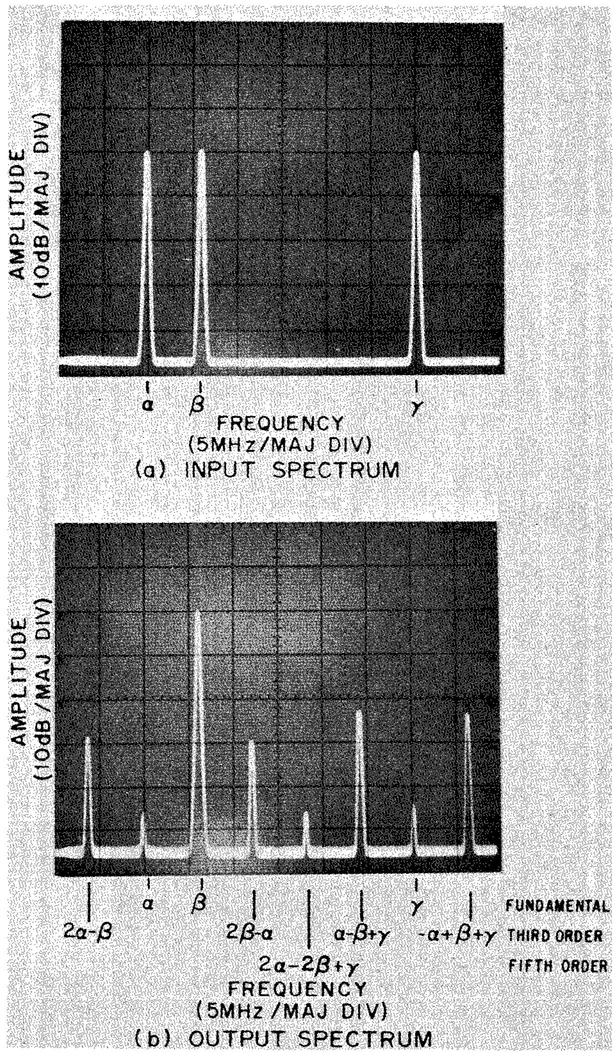

Fig. 2-Input/Output Spectra of Device Under Test

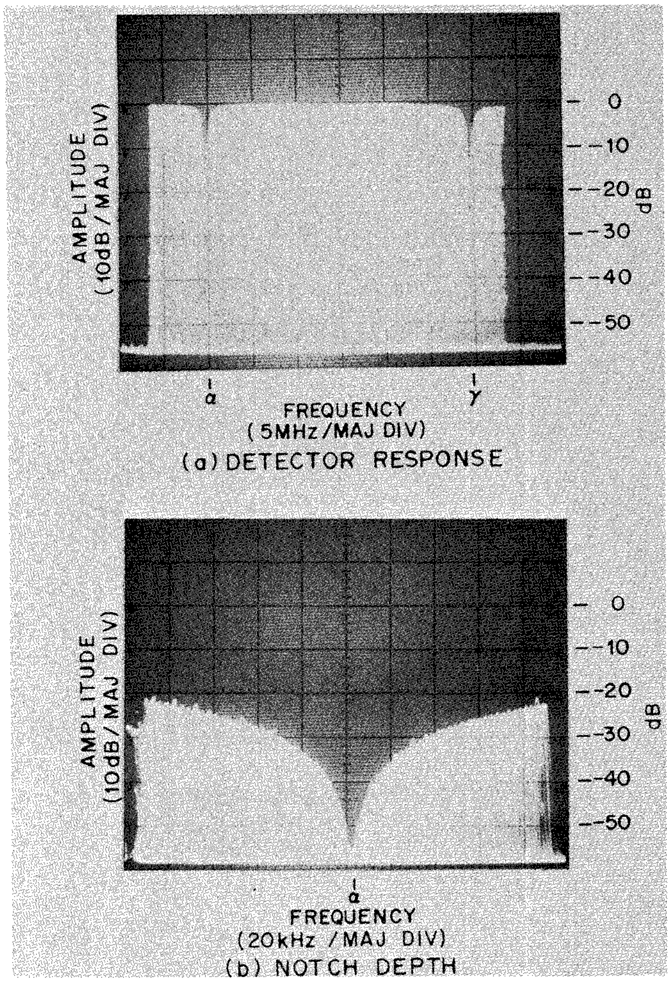

Fig. 3-Detector Transmission Characteristic

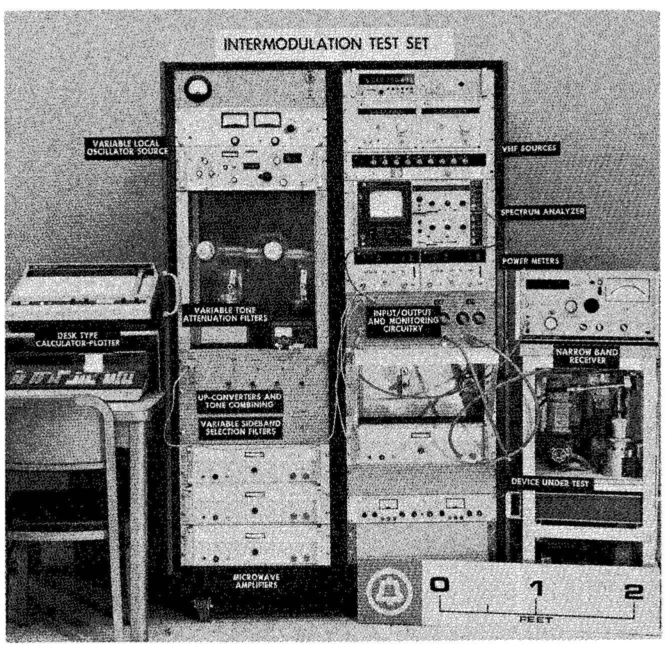

Fig. 4-Complete Intermodulation Test Set-up Measuring 6 GHz Traveling-Wave Tube

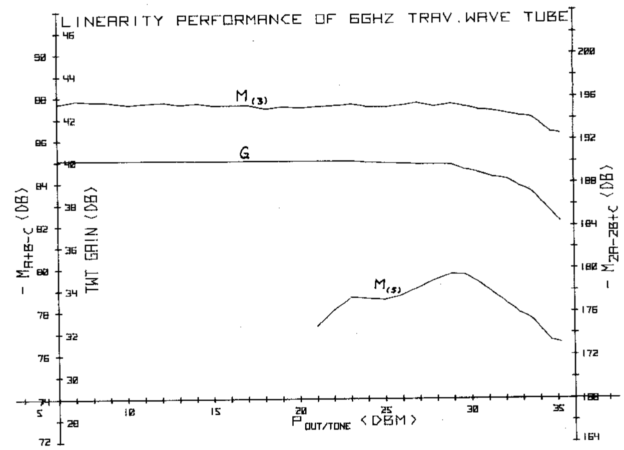

Fig. 5-Typical Plot of Third-and Fifth Order Intermodulation Test Results