# A high dynamic range extension for antenna measurements in the mm-wave range

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## Abstract

A simple extension is presented for measuring antennas coherently in the millimeter-wave frequency range. It is based on the application of harmonic mixers both in the reference path as well as in the measurement path of a lower frequency vector network analyzer. For these measurements, the network analyzer is operated in the "multiple source mode". Harmonic mixers were realized for the frequency ranges from 33 – 40 GHz, 56 – 60 GHz, and 75 – 82 GHz using finline techniques. Testing the complete system, a dynamic range between 50 dB and 80 dB was achieved, meeting the requirements of most measurements. This system therefore can be regarded as an interesting alternative to expensive millimeter-wave vector network analyzers.

## Zusammenfassung

Es wird eine vergleichsweise einfache Erweiterung für vektorielle Antennenmessungen im Millimeterwellenbereich vorgestellt. Sie beruht auf dem Einsatz von Oberwellenmischern sowohl im Referenz- als auch im Meßzweig eines vektoriellen Netzwerkanalysators niedrigerer Frequenz. Der Netzwerkanalysator wird dabei im "Multiple Source Mode" betrieben. Für die Frequenzbereiche 33 – 40 GHz, 56 – 60 GHz und 75 – 82 GHz werden integrierte Oberwellenmischer in Finleitungstechnik realisiert. Im Gesamttest werden Dynamikbereiche von 50 – 80 dB erreicht, was für die meisten Messungen völlig ausreicht. Damit stellt dieses System eine interessante Alternative zu teuren Millimeterwellen-Netzwerkanalysatoren dar.

## Introduction

Typical microwave antenna measurement systems based on a vector network analyzer work on a principle as shown in **Fig. 1** (top). In the basic version, they can be operated up to 26.5 GHz, 40 GHz or 50 GHz; an extension to higher frequencies, however, may be rather expensive. A low-cost detector based measurement system, on the other hand, mostly suffers from a low sensitivity. Therefore, a cost-effective solution for a frequency extension was developed, maintaining a coherent measurement principle. Its principle based on harmonic mixers easily can be extended even into the sub-millimeter-wave range. This not only gives an improved sensitivity (dynamic range of up to 80 dB) and means for phase measurements of antennas, e.g. for determining the phase center of antennas, but also the possibility to use the antenna range for measurements of radar cross section (doing a calibration of the measurement surrounding first and correcting the target measurement with respect to antenna chamber reflections), or to use the measurement system as a network analyzer or as radar simulator as well.

## System considerations

A general block diagram of the modified antenna measurement system is given at the bottom of Fig. 1. Harmonic mixers are used to downconvert both reference and measurement signals. The network analyzer is operated in a mode normally used for mixer characterization (multiple source mode, [1]), thus, two different frequencies can be adjusted. Using reasonably good harmonic mixers and a low noise amplifier for the downconverted receive signal, sensitivity is quite good or even better compared to the original measurement range.

In the example describe here, a system working up to 26.5 GHz was extended for measurements around frequency ranges of practical interest, i.e. 35 ... 38 GHz, 58 ... 60 GHz, and 76 ... 77 GHz. Bandwidth should be as large as possible, and the order of harmonic mixing as low as possible.

At the beginning, numerous frequency combinations for RF, LO, and IF were investigated to avoid spurious signals and critical coupling of unwanted mixing products. As a high dynamic range of the system was intended, coupling of undesired mixing products from the reference mixer (at the transmitter) to the transmit antenna as well as to the receiving mixer via the LO path should be well below –60 dB. As a result, the frequency bands listed in **Table I** were identified.

## Design and results of the harmonic mixers

All harmonic mixers are realized using a double diode configuration to suppress automatically part of the undesired harmonic mixing products [2]. For the Ka- and W-band mixers with even harmonic mixing of order 2 and 4, respectively, configurations with antiparallel diodes were employed (**Fig. 2**). In V-band with a third harmonic mixing, two diodes were used in a 180° hybrid formed by a slot/coplanar line junction (**Fig. 3**). As the typical RF input is waveguide, a planar finline configuration with a taper to standard waveguide was selected for the input, combined with coplanar line, microstrip and suspended stripline. Microstrip was used for the IF low pass filters, suspended stripline for the LO band pass filters [3]. In cooperation with a different project, the V-band mixer was optimized using a full-wave FDTD method [4].

To this extent, the diodes were replaced by their large signal equivalent circuit and a finite diode size and included in a large signal FDTD simulation with sinusoidal LO signal. On the basis of this simulation, a LO matching network was designed. Following this, a small signal modulated Gaussian pulse was injected into the RF input (with steady state sinusoidal LO excitation), and a bandpass type input impedance matching was designed on this basis [4]. Bandpass filter losses and some problems with the transition between the filter and the coaxial connector, however, increased the conversion loss.

The basic layout of this optimized mixer is displayed in Fig. 3; a photograph of the opened split block mount is shown in **Fig. 4**.

| | | | |
|---|---|---|---|
| RF frequency band | 33 - 40 GHz | 56 – 65 GHz | 75 – 82 GHz |
| LO frequency band | 14.5 – 17.5 GHz | 17.3 – 20 GHz | 16.75 – 19.25 GHz |
| Order of harmonic mixing | 2 | 3 | 4 |
| IF frequency band | 4 – 5 GHz | | |

**Table I:** Frequency schedule for the measurement extension.

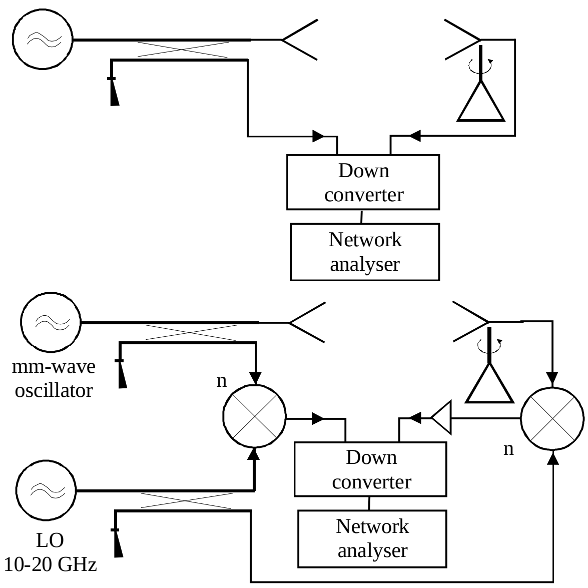


**Fig. 1:** Block diagram of original (top) and extended (bottom) antenna measurement system.

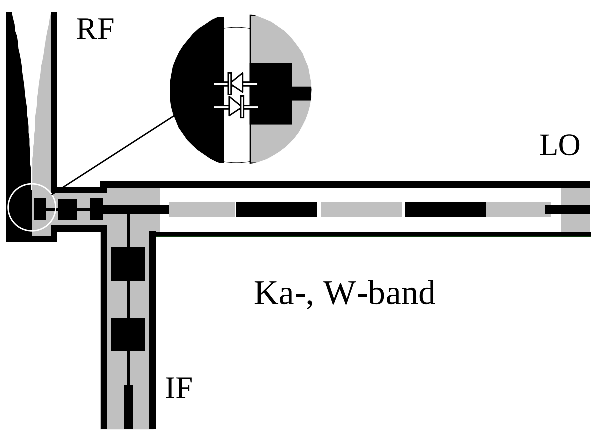


**Fig. 2:** Basic layouts of the harmonic mixers for Ka- and W-band. (Black: front side metallization, grey: back side metallization).

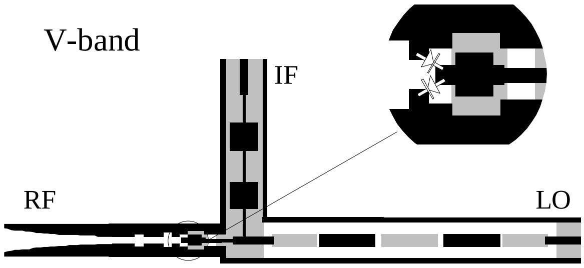


**Fig. 3:** Basic layouts of the V-band harmonic mixer. (Black: front side metallization, grey: back side metallization).

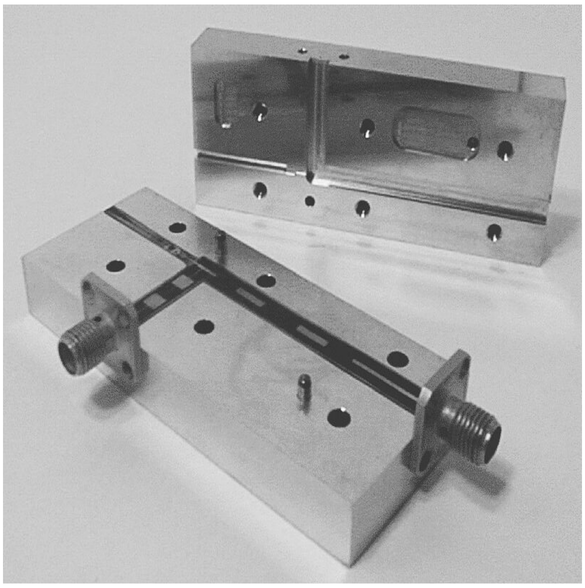

**Fig. 4:** Photograph of the opened split block mount of the V-band harmonic mixer.

The conversion loss of all three mixers is plotted in **Fig. 5**. Except for the Ka-band mixer, a relative large variation of the conversion loss can be stated; this, however, is due to adjustments of LO and IF frequencies as a function of input frequency and to some uncertainties in power measurements at RF and IF frequency.

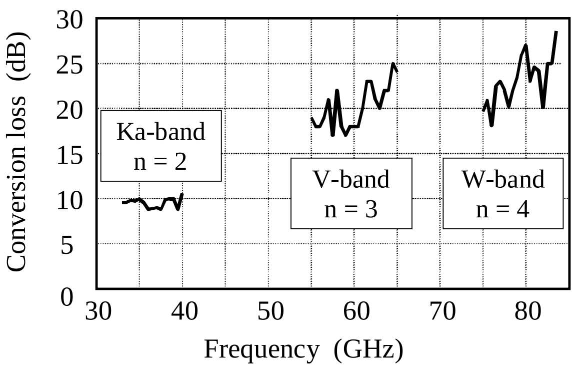


**Fig. 5:** Conversion loss of the harmonic mixers.

## Results of antenna test measurements

To test the performance, a number of antennas were measured in the selected frequency ranges. For the 38 GHz frequency range, a Ka-band sweeper was used as measurement source, at V- and W-band, a sweeper up to 20 GHz followed by multipliers – by a factor of 4 for V-band and by 6 in W-band. Transmitter powers were about 10 mW in Ka-band, 1 – 2 mW in V-band and 0.5 mW in W-band. Measurement distance was 6 m.

**Fig. 6** shows the superposition of four measurements of a parabolic reflector with different transmission power levels adjusted by an attenuator inserted in the transmitter path, but normalized to 0 dB at the respective maximum of the diagram. Some noise floor can be recognized at a level of –30 dB ... –40 dB for the measurement with 30 dB and 40 dB attenuation. As a whole, however, a dynamic range of 60 – 70 dB with excellent linearity can be found.

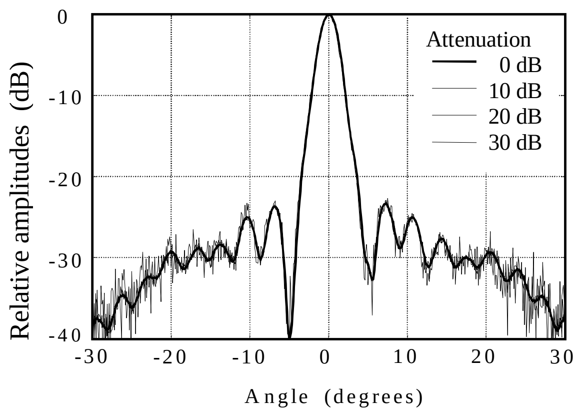


**Fig. 6:** Radiation diagrams of a parabolic reflector at 36 GHz with different input attenuation levels (including some averaging at the higher attenuation).

Best results were achieve with the V-band measurement setup. **Fig.7** shows the radiation diagrams of a parabolic reflector at 60 GHz (reflector diameter 200 mm; with a measurement distance of 6 m, far field conditions were not given). The gain of this antenna and the included system gain was such that the maximum measured received signal was at the upper limit of the linear range. Measurements were done with different attenuation values at the RF input. On the top of Fig. 7, the original measurements are displayed, while on the bottom, all four diagrams were normalized to 0 dB at 0° angle and superimposed. An excellent linearity and a dynamic range of up to 80 dB can be stated.

At 78 GHz, a horn antenna with 40 mm diameter including a lens was tested, once again with different attenuation levels in the transmit path. The respective radiation diagrams are plotted in **Fig. 8**. A linear dynamic range of nearly 60 dB can be seen. The peak power level without attenuation did not reach the maximum allowable amplitude at the receiver; thus the dynamic even can be higher using an antenna with higher gain or a transmit source with higher power.

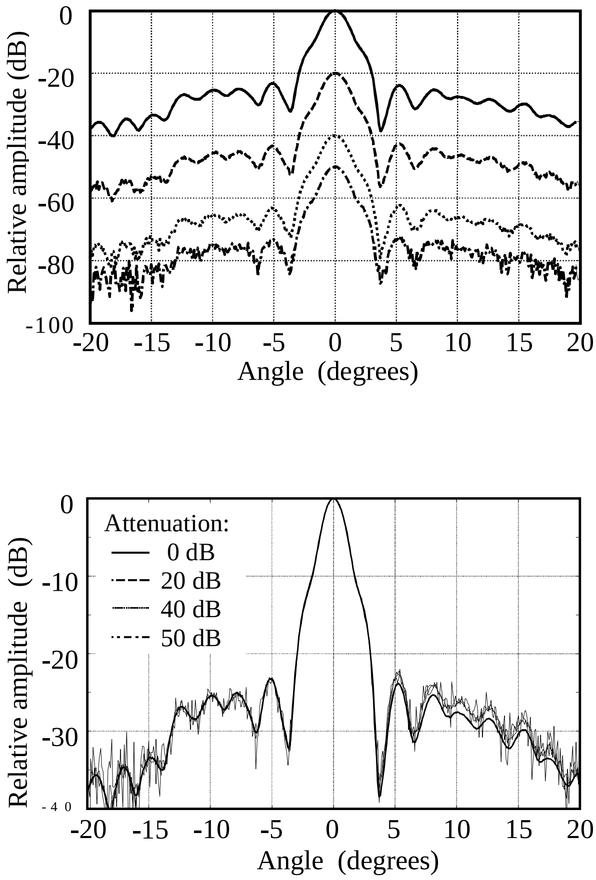


**Fig. 7:** Radiation diagrams of a parabolic reflector at 60 GHz with different input attenuation levels.

*Top:* All measurements are normalized with respect to the maximum of the measurement with 0 dB attenuation.

*Bottom:* All measurements are normalized on the basis of their respective maximum

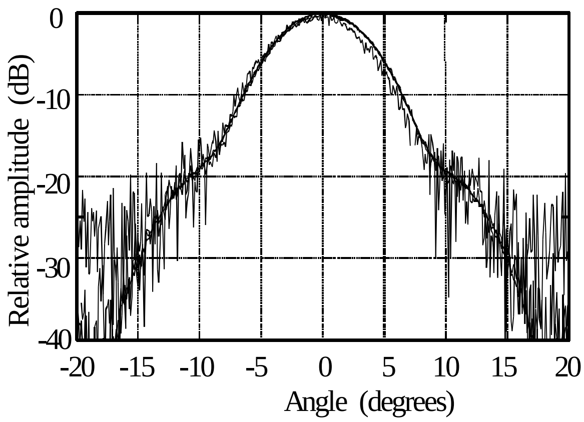


**Fig. 8:** Radiation diagrams of a horn/lens combination at 78 GHz with 0 dB, 10 dB, 20 dB, and 30 dB input attenuation level.

## Conclusion

A simple but effective arrangement has been described to extend the frequency range of network analyzer based antenna measurement equipment to the higher mm-wave range using harmonic mixers and the multiple source option of the network analyzer. The harmonic mixers were realized using planar circuits in a waveguide channel. Good sensitivity was achieved up to more than 80 GHz, but the principle easily can be extended to even higher frequencies.

## References

[1] Hewlett-Packard: Product Note 8510-7: Microwave Component Measurements, September 1987.

[2] Schmidt, L.-P.; Menzel, W.: Planar Integrated Harmonic Mixers for Use up to 150 GHz. MIOP'87, 19.-21.05.87, Proc. Vol. 1, Session 4A-4.

[3] Schwab, W.; Bögelsack, F.; Menzel, W.: Multilayer Suspended Stripline and Coplanar Line Filters. IEEE Trans. on MTT, July 1994, 1403-1407.

[4] Thiel, W., Menzel, W.: Full-wave design and optimization of mm-wave diode-based circuits in finline technique. IEEE Trans. on Microw. Theory Tech., Vol. MTT-47, No. 12 (Dec. 1999), pp. 2460 – 2466.