IMPROVED MILLIMETER WAVE SIGNAL ANALYSIS

AUTHOR:
FRANK DAVID

SIGNAL ANALYSIS DIVISION
1424 FOUNTAIN GROVE PARKWAY
SANTA ROSA, CA 95401

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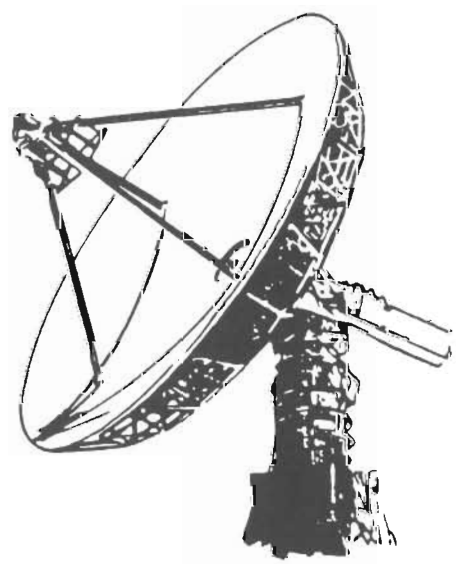

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NEED FOR IMPROVEMENT

- MIXER LIMITATIONS
- SYSTEM LIMITATIONS

NEW MIXER TECHNOLOGY

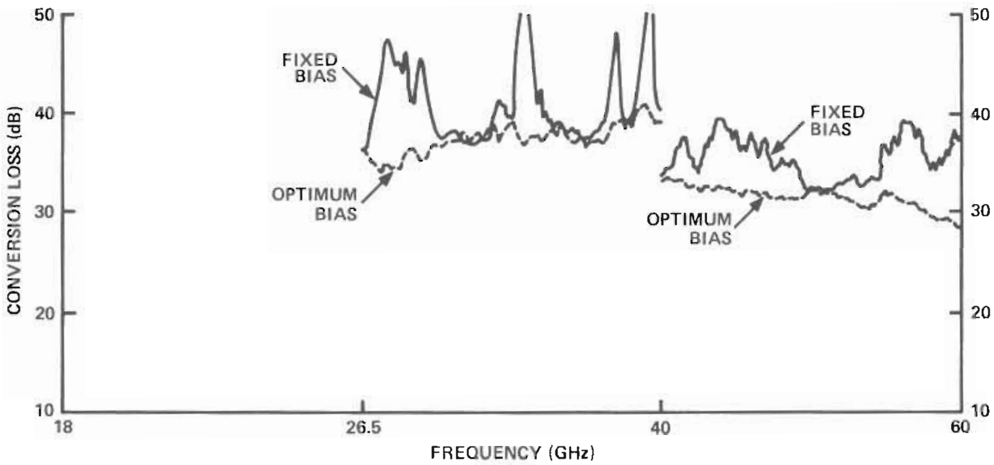
- PERFORMANCE
- DESIGN DETAILS

IMPROVED MEASUREMENTS

- BETTER SYSTEM PERFORMANCE
- EXPANDED CAPABILITY

There are three sections to today's presentation. First, the need for improvement will be established by reviewing some of the important performance characteristics of existing single-diode, biased harmonic mixers and spectrum analyzers. Second, the performance and design details of unbiased, harmonic mixers will be described. Third, we will look at how these new mixers work with our spectrum analyzers to improve mm-wave signal analysis by providing better system performance.

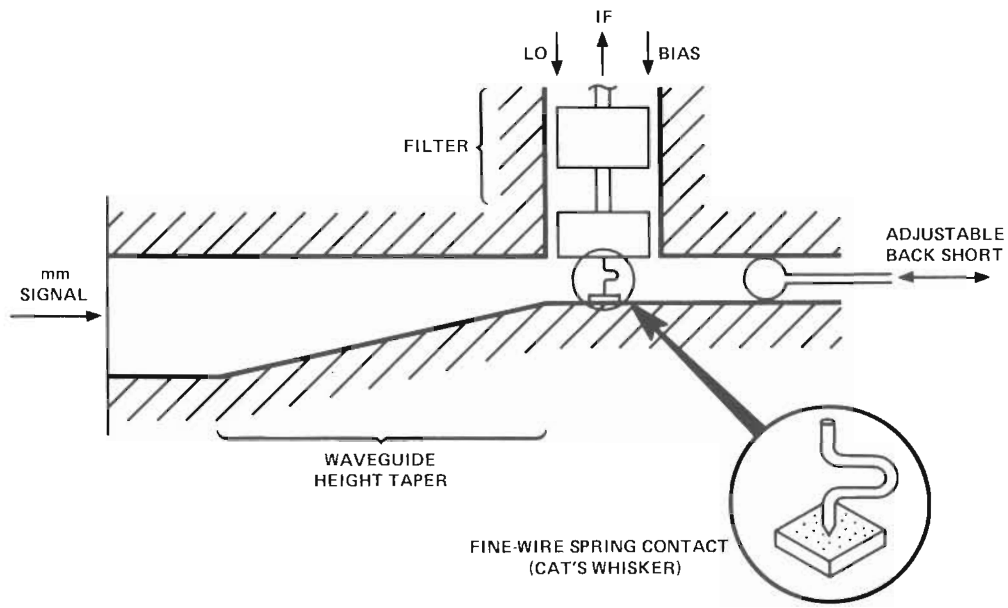
BIASED MIXER PERFORMANCE



- OPTIMUM DIODE BIAS IS REQUIRED FOR LOWEST L_C AND BEST FLATNESS
- POOR FLATNESS WITH FIXED BIAS
- HIGH CONVERSION LOSS EVEN WITH OPTIMUM BIAS

Some of the performance limitations of single-diode, biased, harmonic mixers are evident on this graph which shows the measured conversion loss of two commercially available mixers that are representative of the current performance. Note that the full-band flatness is very poor unless the diode bias is adjusted to its optimum value at each frequency. This adjustment is sensitive: often a bias current change of 500 microamps or less can cause a change in conversion loss of 5 dB, or more. Even with optimized bias, the mixer's conversion loss is relatively high.

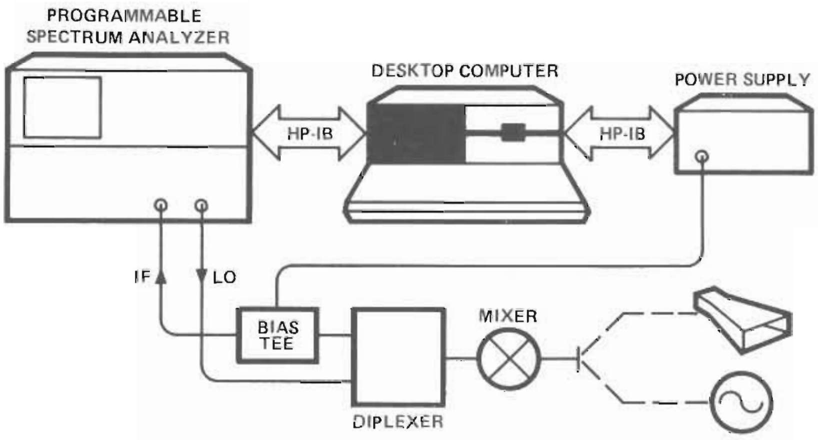
SINGLE-DIODE, BIASED MIXER CHARACTERISTICS



This diagram of a single-diode, biased mixer is representative of this type of harmonic mixer; all commercially available mixers have some or all of the features shown.

Most mixers do not have point-contact diodes, but they still use the fine-wire point contact to achieve low parasitics in making the electrical connection to the diode. This connection, along with the adjustable back short, give this type of mixer a reputation for mechanical fragility.

MEASUREMENT LIMITATIONS OF BIASED MIXERS

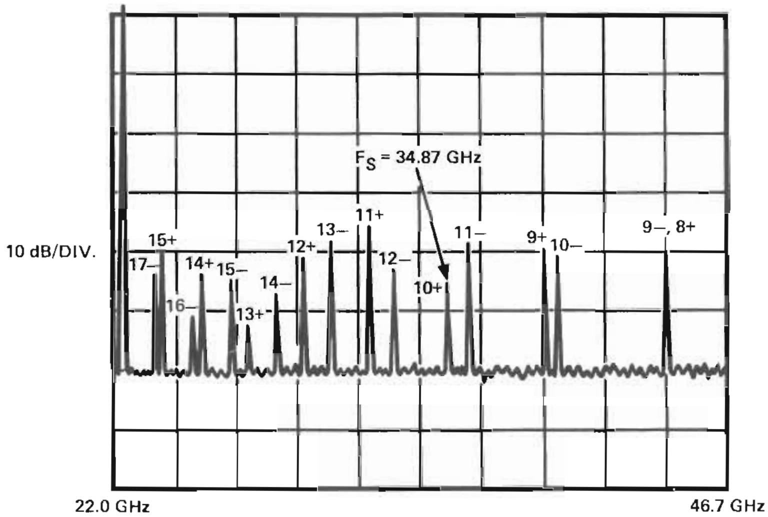


- DIFFICULT SWEPT MEASUREMENT
  - POINT BY POINT MEASUREMENT
  - BIAS MUST BE PEAKED AT EACH POINT
  - SLOW
- INACCURATE AMPLITUDE MEASUREMENTS
  - MIXER FREQUENCY RESPONSE + VARIATION OF AVERAGE CONVERSION LOSS RESULTS IN ≥5 dB AMPLITUDE UNCERTAINTY

As illustrated by this typical test setup, a "swept" measurement using a biased diode mixer requires some additional equipment. This additional equipment does allow an automated, broadband measurement to be made; but the need to peak the bias at each measurement frequency makes the measurement slow.

Once the measurement is made, the amplitude information has a relatively high level of uncertainty due to the combination of the mixer's flatness and variation of average conversion loss.

DIFFICULT SIGNAL IDENTIFICATION



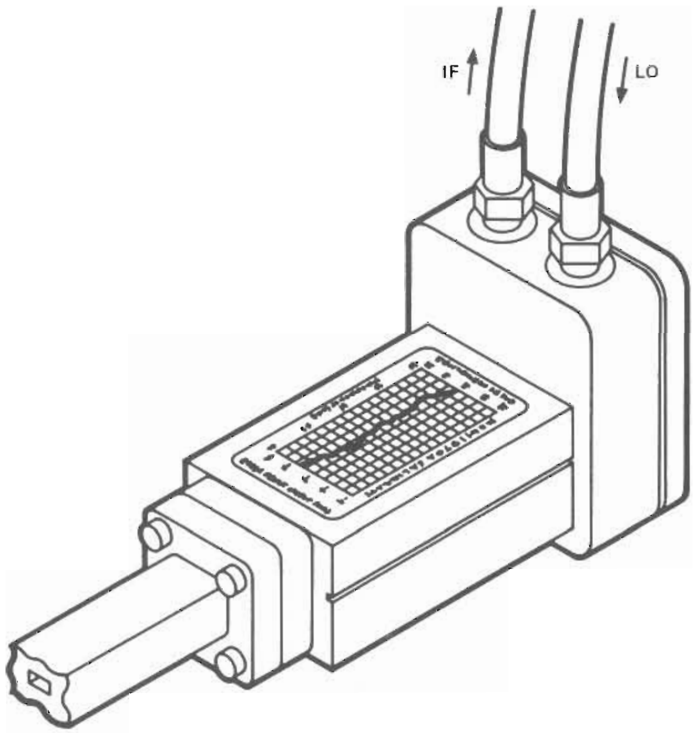
SIGNAL ID ROUTINE

1. WIDEN SCAN TO VIEW RESPONSE OVER BAND OF INTEREST
2. CHOOSE LIKELY RESPONSE AND CENTER ON SCREEN
3. NARROW THE SCAN TO 1 MHz/DIV. WHILE RE-CENTERING THE RESPONSE
4. PRESS SIGNAL I.D. BUTTON
5. IF I.D. IS INCORRECT, GO BACK TO 1

This full-span output from the screen of a spectrum analyzer with a 2050 MHz IF shows a number of harmonic responses produced by only one signal at 34.87 GHz. Only one of these responses is frequency calibrated for this band and it is up to the operator to determine it. If the operator doesn't know the exact frequency of the signal, then a signal identification routine must be carefully performed.

This display shows another difficulty that is subtle but very real and troublesome: the correct response may be in the noise due to the diode bias "notching it out". Thus it is necessary to insure no responses are lost in the noise due to improper bias.

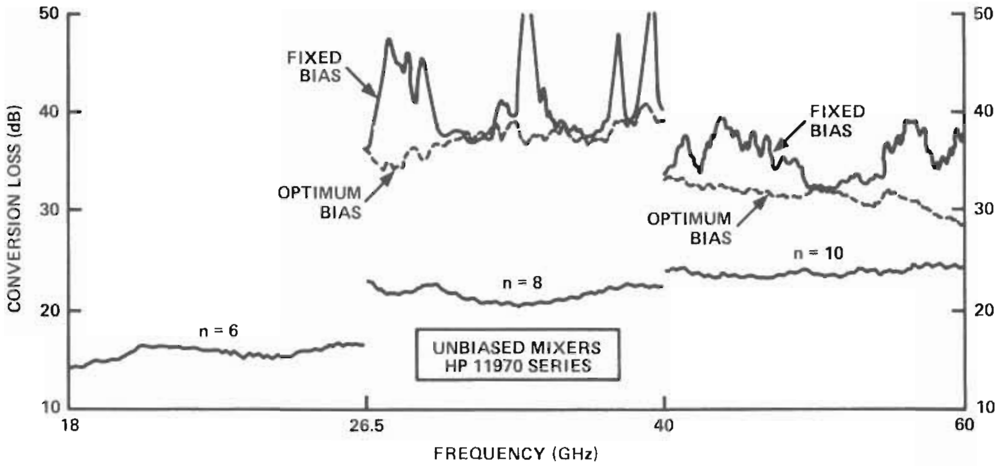
11970A UNBIASED HARMONIC MIXER



Introduction of the unbiased, full-band, harmonic mixers begins with a look at the 11970A which covers the 26.5 to 40 GHz waveguide band. The 11970A's size and shape is representative of the mixers that cover the other waveguide bands.

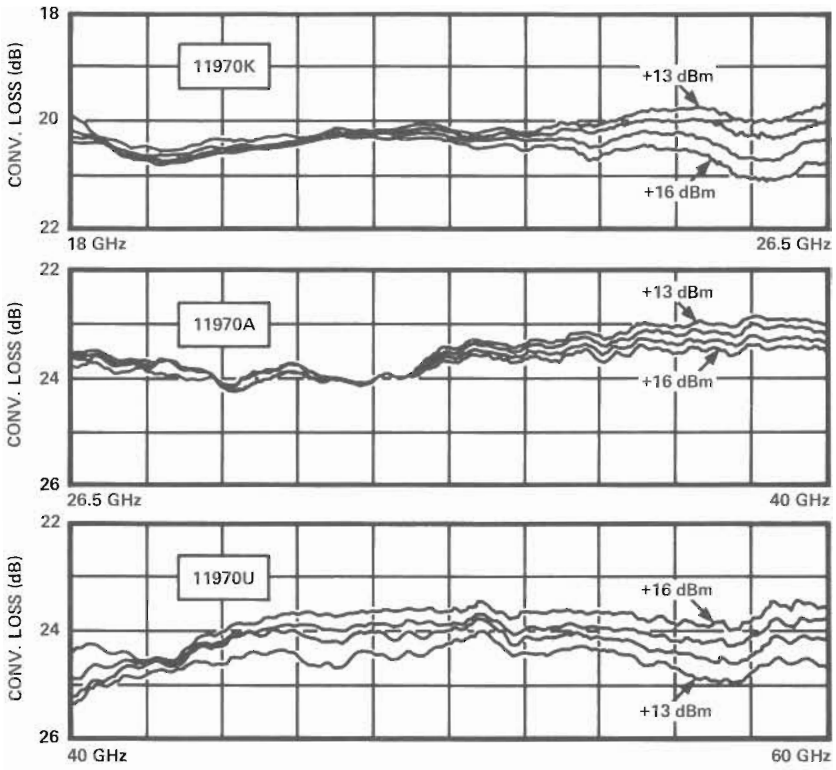
All necessary waveguide tapers and LO/IF diplexer circuitry are integrated into one package. This aluminum package is lightweight, mechanically rugged and relatively compact. Included on each package is a calibration label that shows the mixer's conversion loss vs. frequency.

CONVERSION LOSS COMPARISON



Here is the conversion loss for the 11970 K, A, and U mixers over their full waveguide bands. In a comparison with the performance of a biased mixer, the unbiased mixers have improved flatness and lower conversion loss.

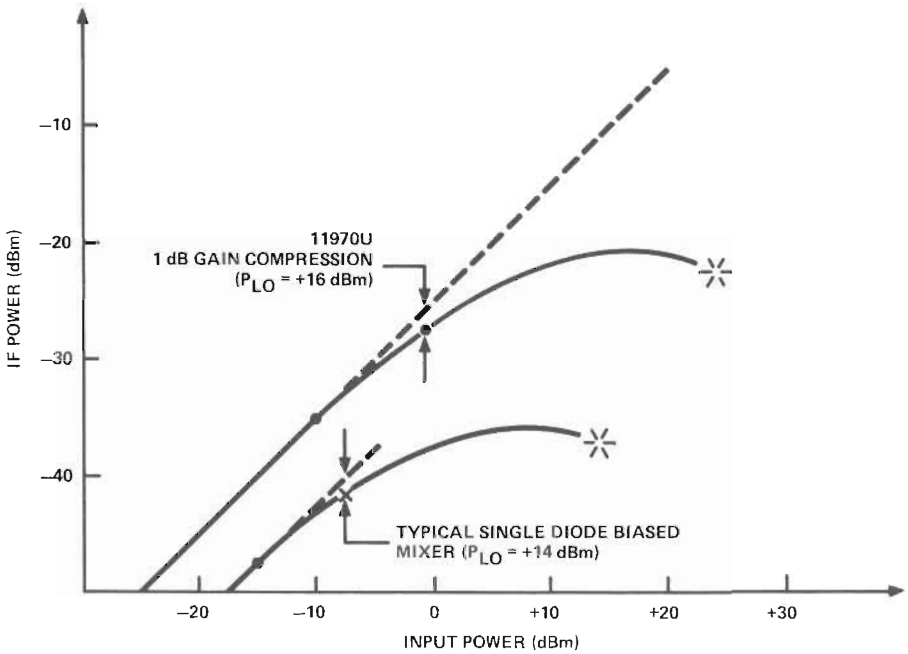
CONVERSION LOSS/LO SENSITIVITY



A closer look at conversion loss vs. frequency shows both the smoothness of this response and how little it changes over a wide variation of LO input power.

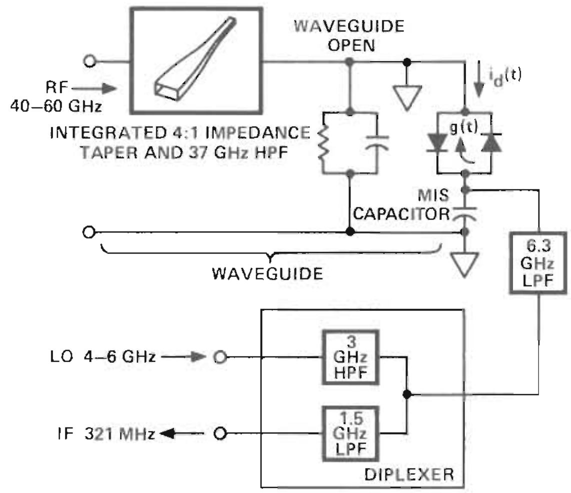
The relatively high levels of LO power required are due to a combination of the high harmonic numbers used for the mixing and the characteristics of the mixing diodes. This will be examined in more detail later.

PERFORMANCE WITH HIGH INPUT POWER



The unbiased mixers are more electrically rugged than a single-diode, biased mixer which has typical gain compression and burn-out levels as shown.

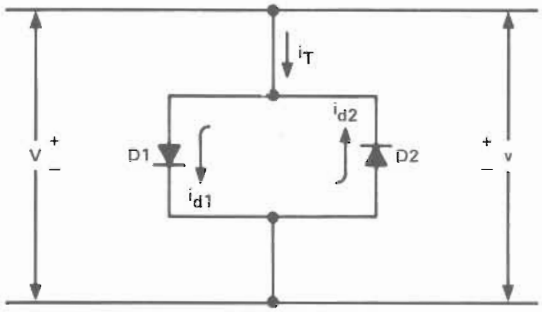
11970U MIXER SCHEMATIC



A look at the technical details of the mixer's design starts with the schematic of the 11970U which shows the key features: the mixing diodes are an anti-parallel pair; the waveguide input has both height and width tapers; the mixing diodes are the termination for the otherwise open end of the waveguide's output; the input signal and many high-order harmonics are confined to the immediate vicinity of the diodes by the 6.3 GHz low pass filter whose first element is a resonance free Metal-Insulator-Semiconductor (MIS) capacitor; the LO and IF frequencies are separated by a diplexer circuit with cutoff frequencies shown.

As we go on, each of these features will be examined in more detail to point out their contribution to the mixer's improved performance.

MIXING PRODUCTS OF ANTI-PARALLEL DIODES



V = LO VOLTAGE ACROSS DIODES
v = INPUT SIGNAL VOLTAGE ACROSS DIODES

TERMINAL CURRENT = $i_T = i_{d1} - i_{d2}$

$$i_T = g_1 (V + v) + (g_{30}V^3 + g_{21}V^2v^1 + g_{12}Vv^2 + g_{03}v^3) + (g_{50}V^5 + g_{41}V^4v + g_{32}V^3v^2 + g_{23}V^2v^3 + g_{14}Vv^4 + g_{05}v^5) + (\dots + g_{61}V^6v + \dots) + (\dots + g_{81}V^8v + \dots) + \dots$$

LOOP CURRENT = $i_L = i_{d1} + i_{d2}$

$$i_L = I_0 + (g_{20}V^2 + g_{11}Vv + g_{02}v^2) + (g_{40}V^4 + g_{31}V^3v + g_{22}V^2v^2 + g_{13}Vv^3 + g_{04}v^4) + (g_{60}V^6 + g_{51}V^5v + \dots) + \dots$$

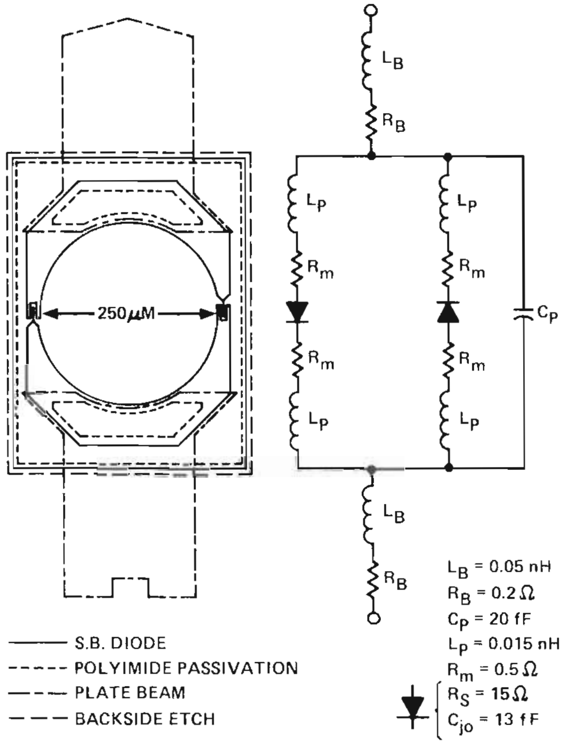
To find which components of current flow through the two terminals of the diode pair (terminal currents) and which stay in the diode loop (loop currents), the current in each diode, i_{d1} and i_{d2}, is expanded in a Taylor series of two independent variables, V and v (Ref. 1). Assuming perfect diode match, term-by-term subtraction and addition of these series yields i_T and i_L respectively.

Since the IF current can only contain components of i_T, there are several important things to learn from this exercise:

- The IF can only have mixing products of the input signal with the **even** harmonics of the LO.
- The **odd** harmonics of the LO can flow in external circuitry, the **evens** are confined to the loop - this includes the d.c. component.
- The fundamental mixing product stays in the loop and cannot dissipate energy in external circuitry, hence higher efficiency for even harmonic mixing since the loop currents re-mix with the LO to add to the components of i_T.

Diode mismatch will allow the components of i_L to join i_T to a degree limited by the amount of the mismatch.

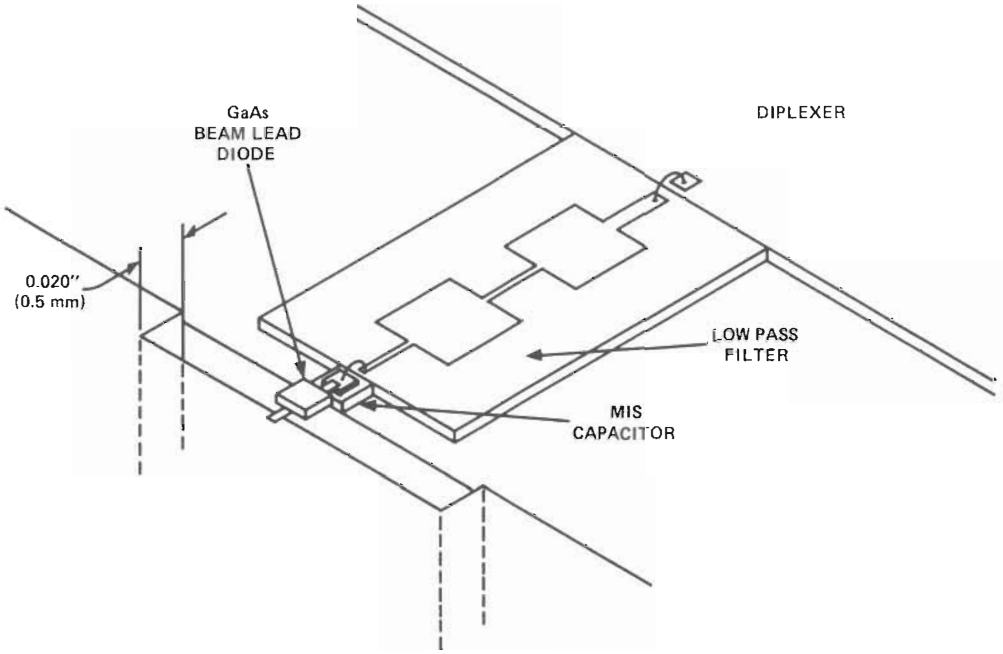
BEAM-LEAD GaAs DIODE



Two anti-parallel diodes have been integrated on one chip of Gallium Arsenide with gold beam leads attached to facilitate circuit mounting (Ref. 2).

Some of the details of the diode's construction and parasitics are shown here. An important point is that this beam-lead diode achieves low parasitics with a physically rugged structure.

DIODE MOUNTING

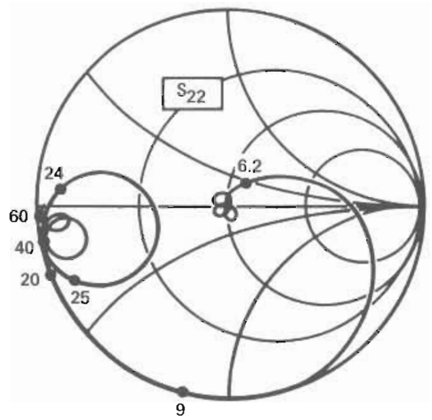


To minimize connection reactance for good flatness, the waveguide height has been reduced to .020 inches (.5mm) and the diode is mounted across it. This layout is simple and compatible with long-proven microelectronic assembly techniques; this results in a mechanically rugged and reliable connection between the diode and its associated circuitry.

LOW PASS FILTER CHARACTERISTICS

THIS IMPORTANT ELEMENT PERFORMS SEVERAL FUNCTIONS

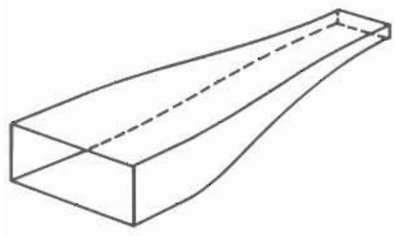
- PROVIDES LOW LOSS TO THE FUNDAMENTAL OF THE LO SIGNAL
- APPEARS AS A SHORT CIRCUIT TO THE INPUT SIGNAL AND ALL THE HARMONICS OF THE LO



11970U
6.3 GHz
LOW PASS FILTER

To provide a flat conversion loss vs. frequency response, the low pass filter connected to the diode must have a well controlled reflection characteristic over a frequency range that starts at the second harmonic of the lowest LO frequency and extends beyond the upper frequency of the waveguide band. The only hope of avoiding a major resonance in S_{22} over such a broad range is to make the first element of the filter a resonance-free shunt capacitor so that it can short out the resonances of the other elements of the filter.

WAVEGUIDE TAPERS

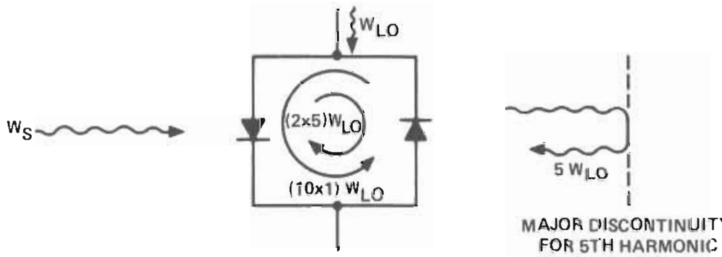


HEIGHT TAPER

- MODIFIED EXPONENTIAL TAPER FOR WAVEGUIDE TO DIODE IMPEDANCE MATCH

WIDTH TAPER

- HIGH PASS FILTER FOR HARMONIC CONTROL

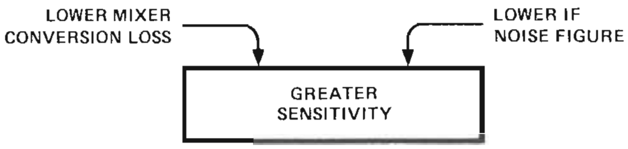


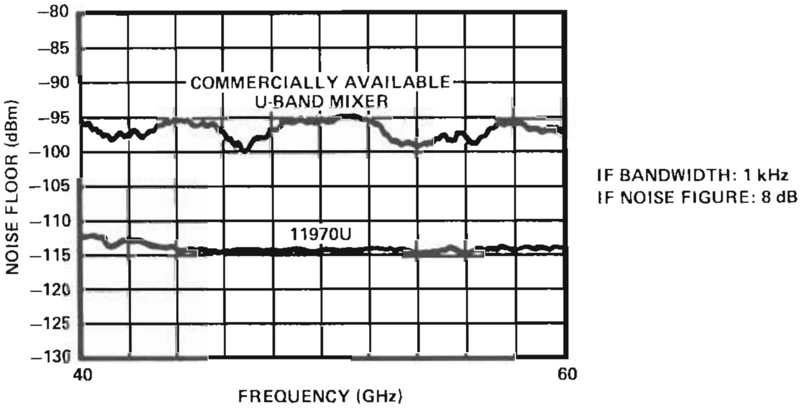
The height and width tapers are integrated into the same section of waveguide to keep the mixer package as compact as possible.

The height taper provides both a physical transition from the standard, full-height rectangular waveguide to the reduced height waveguide and an impedance transformation from the high impedance of the full-height waveguide to the low, dynamic impedance of the diode (less than 50 ohms). Along the tapers length, the height changes to create a modified exponential impedance variation (Ref. 3); this gives the transformer a near-optimum condition of low reflection and short length.

The width taper creates a high-pass filter in the waveguide that controls destructive interference from reflections of the LO's odd harmonics. The troublesome harmonics are reflected, in phase, at the plane of the diode's location, and hence re-enter and re-mix in the diode in a constructive manner with the desired harmonics in the diode loop. Along the taper's length, the width changes in a manner that follows an exponential-to-cosine-cubed impedance variation to give low reflection and short length (Ref. 4).

IMPROVED SYSTEM PERFORMANCE: SENSITIVITY

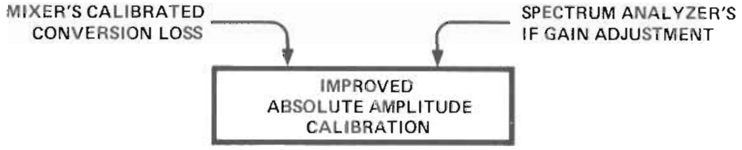


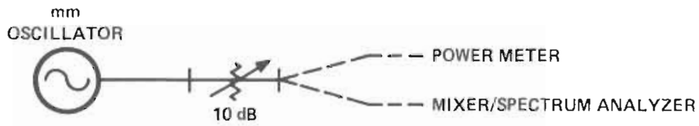


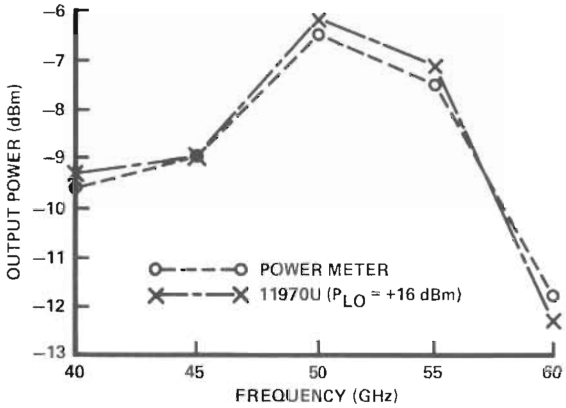
The combination of lower mixer conversion loss and a lower IF noise figure contribute to improved measurement sensitivity. Lower IF noise figure results from using a lower IF frequency (321 MHz vs. 2.05 GHz) and avoiding an additional frequency down conversion.

The noise floors shown here are what would be displayed on the analyzer's screen if the IF gain was adjusted at each frequency to keep a constant amplitude input signal at a fixed reference level.

IMPROVED SYSTEM PERFORMANCE: AMPLITUDE CALIBRATION

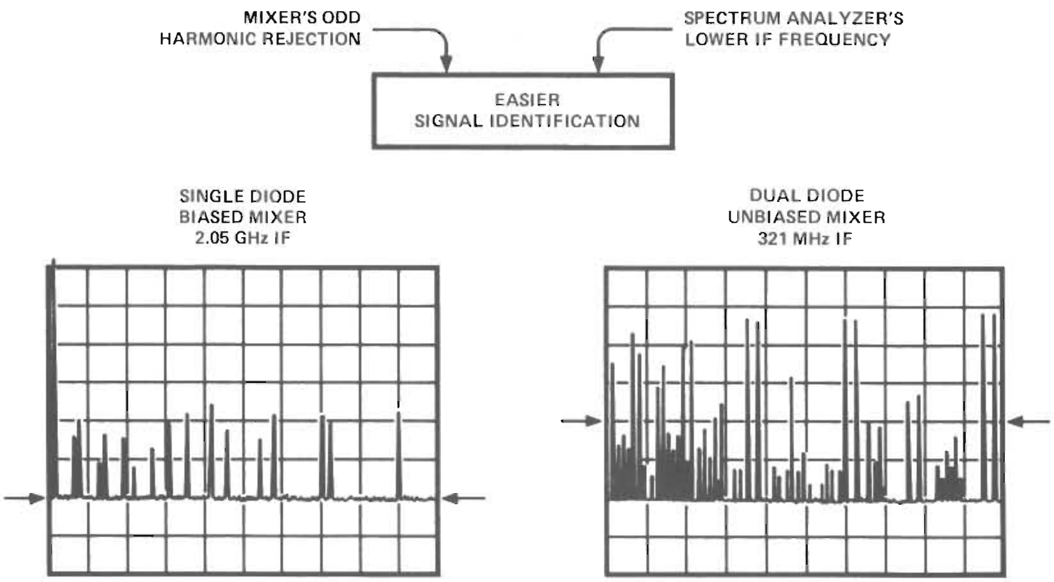






Using the calibration label on the 11970U to correct the measured data gives a result that is very close to the power meter's result (typical for the HP 8566A and HP 8569B).

IMPROVED SYSTEM PERFORMANCE: SIGNAL IDENTIFICATION

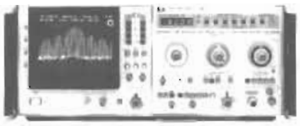


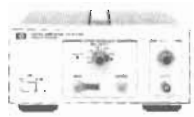
Due to the lower 321 MHz IF frequency, the pairing of the mixing products is easy to see, and the mixer's odd harmonic rejection (typically 20-30 dB) makes it easier to find the even harmonic responses.

This difference in the displays is typical of both the HP 8566A and 8569B spectrum analyzers, and it means that the probability of finding the correct response on the first or second try is much greater with the dual-diode mixer and 321 MHz IF measurement system.

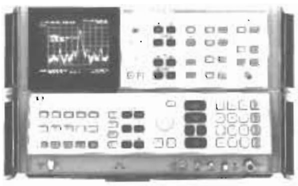
MILLIMETER WAVE SPECTRUM ANALYZERS


HP 11971K
HP 11971A
HP 11971U


HP 8569B


HP 11975A


HP 11970K
HP 11970A
HP 11970U


HP 8566A


HP 11975A

There are two mixer sets currently covering the 18.0 to 60.0 GHz frequency range: the HP 11970K and 11971K 18.0 to 26.5 GHz, the 11970A and 11971A 26.5 to 40.0 GHz, and the 11970U and 11971U 40.0 to 60.0 GHz. The 11971 series of mixers is optimized for the 2.0 to 4.5 GHz LO range of the HP 8569B Spectrum Analyzer. The 11970 series of mixers is matched to the 2.0 to 6.0 GHz LO range of the HP 8566A Spectrum Analyzer. For a particular frequency band, a different LO range requires a different harmonic number, and hence a different mixer for optimum performance. Note the 8569B and 8566A are the only spectrum analyzers currently taking advantage of the lower (321.4 MHz) IF frequency and thus compatible with the 11970/11971 mixers.

The 11975A 2 to 8 GHz amplifier is used to raise the LO power level to approximately +16 dBm where the mixers work best and can be used to offset cable loss when the mixer is used remote from the spectrum analyzer.

REFERENCES

1. R. Joly, "Cancellations in Mixers", HP internal report, 1970.

2. G. Anderson, R. Matreci, et al, "GaAs Beam Lead Antiparallel Diodes for mmw Subharmonic Mixers", International Electron Devices Meeting, Washington, D.C., December, 1981.

3. F. David, "Analysis and Synthesis of Exponentially Tapered, Non-Uniform Transmission Line Impedance Transformers", MSEE Thesis, Oregon State University, 1975.

4. C. Tang, "Non-Uniformn Waveguide High-Pass Filters with Extremely Steep Cutoff", IEEE Transactions on MTT, vol. MTT-12, May, 1964, pp. 300-309.

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