Application Note

Millimeter Scalar Analysis Systems

- Full V or W Band coverage
- Cost effective millimeter capability
- Small, self contained, easy to use
- Millimeter wave capability with existing microwave equipment

- Low spurs and harmonics -50 dBc
- Excellent coupler directivity >37 dB
- Wide dynamic range 50 dB typical
- High output power >0 dBm typical

OML is proud to introduce its new scalar analysis accessories product line with the announcement of the availability of the N20RFT and N21RFT reflection coefficient measurement reflectometers and the N20DET and N21DET transmission (insertion loss) detectors for V and W Band operation. The reflectometers contain multiplier sources, x4 for V Band (50 to 75 GHz), and x6 for W Band (75 to 110 GHz). These multiplier sources are complete with all of the necessary components including: a doubler/driver amplifier, a x2 or x3 final multiplier and all necessary filters. The source module in each of the reflectometer models is terminated with a full band isolator to achieve a good source match. Each reflectometer also contains a high directivity dual directional coupler, a reference detector for ratioed measurements or signal leveling, and a reflection detector for return loss measurement. Each detector output is linearized to provide excellent accuracy over it's entire dynamic range. The transmission detector is also linearized, and is equipped with a full band isolator to provide excellent accuracy with minimum "device under test" interaction.

The OML reflectometer sources are exceptionally clean, utilizing extensive filtering to achieve harmonic and spurious suppression of greater than 50 dB. These sources are designed to function with **any manufacturer's sweep generator** capable of providing **+7 dbm output power** across the specified reflectometer's input frequency range. The primary focus of the reflectometer design effort was to maximize the output power while maintaining excellent spurious and harmonic suppression. To achieve good power over full waveguide bandwidths, the source final multipliers were designed to use a balanced diode configuration. These multipliers achieve close to theoretical conversion efficiency. The low insertion loss of the filters and isolators make this output power available to the user. Figures 1 and 2 below, illustrate the typical output power available for V and W Band at the reflectometer test port.

Figure 1 OML N20RFT Output Power
FL1 installed

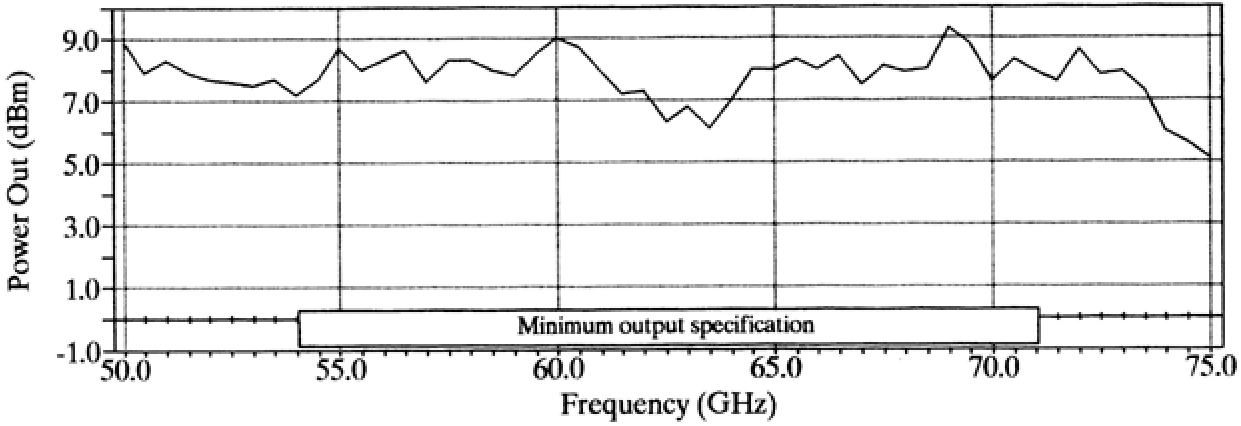
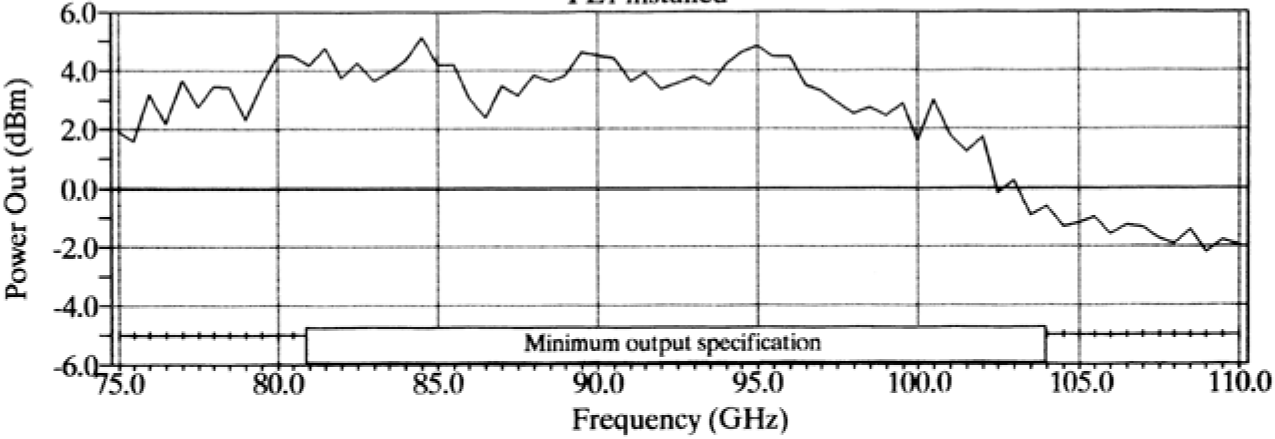


Figure 2 OML N21RFT Power Output
FL1 installed



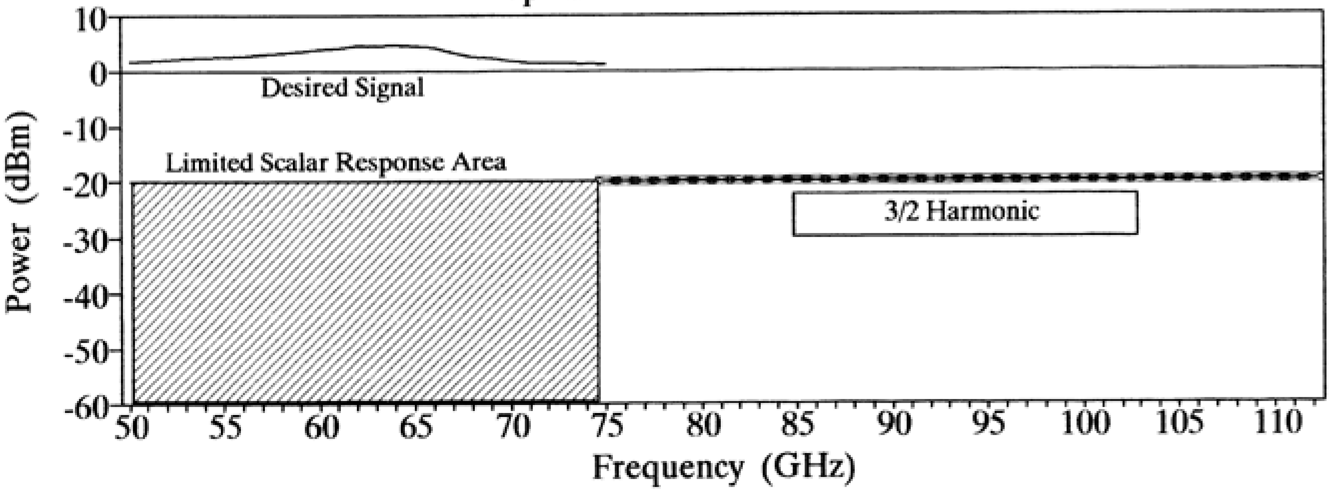
Effects of a 3/2 Harmonic

The stringent design goals established for the sources have resulted in minimal in-band harmonically related spurious signals as well as good power performance. All multiplier schemes suffer from harmonic and spurious product generation, of which the 3/2 harmonic is the most damaging. The final multiplier's 3/2 harmonic (3x input frequency) is a suppressed output which is typically 15 to 20 dB below the desired output. In the traditional millimeter waveguide bands the 3x product generated by a doubler occurs right at the upper band edge. A good example is in the 50 to 75 GHz band. The intermediate input frequency driving the output doubler is 25 GHz for a desired output of 50 GHz. The 3/2 harmonic falls at 75 GHz . It can be seen that as soon as the input frequency is moved above 25 GHz the 3/2 harmonic is "out-of-band." However, these undesired out-of-band harmonics have severe implications when any multiplier is used as a source for scalar analysis. When a tripler is used the 3/2 harmonic occurs over a much greater portion of the band. In W Band the 3/2 harmonic starts at 100 GHz.

A 50 to 75 GHz scalar analyzer system with a multiplier source will typically use a doubler/doubler combination. In addition to the desired 50 to 75 GHz signal and 3/2 harmonic, many other signals are present. A cure for the 3/2 harmonic problem will lead us into the solutions for in-band and out-of-band spurious signals that are present. **Available detectors for this frequency band will not be able to discriminate between the desired signal and the unwanted 3/2 harmonic** (or other spurious and harmonics). If the user is sweeping a V-Band bandpass filter for return loss, the detector will see not only the reflected 50 to 75 GHz signal of interest, but will also sense the 3/2 harmonic (75 to 112 GHz) signal being reflected . The 3/2 harmonic signal could be at a level approximately 20 dB below the desired signal. Most of this unwanted energy will be reflected by the V-Band bandpass filter and be detected, effectively limiting the scalar analysis dynamic range to 20 dB. Figure 3 on the next page is a graph of output of the 50 to 75 GHz source without output filtering. The extent of the 3/2 harmonic can be easily seen (the shaded region is the impacted band).

To overcome this problem, OML has developed a filtering scheme which suppresses the undesired 3/2 harmonic to greater than -50 dBc. The band is divided into two overlapping segments, 50 to 58 GHz and 57 to 75 GHz (75 to 92 and 89 to 110 GHz for W Band), for which filters FL2 and FL3 are provided. In both V and W Band, **the 3/2 harmonic is eliminated by the use of FL2 or FL3 and by limiting the swept frequency range to the filter bandwidths.**

Figure 3 V-Band Output Power and Spurious Level Without Filter



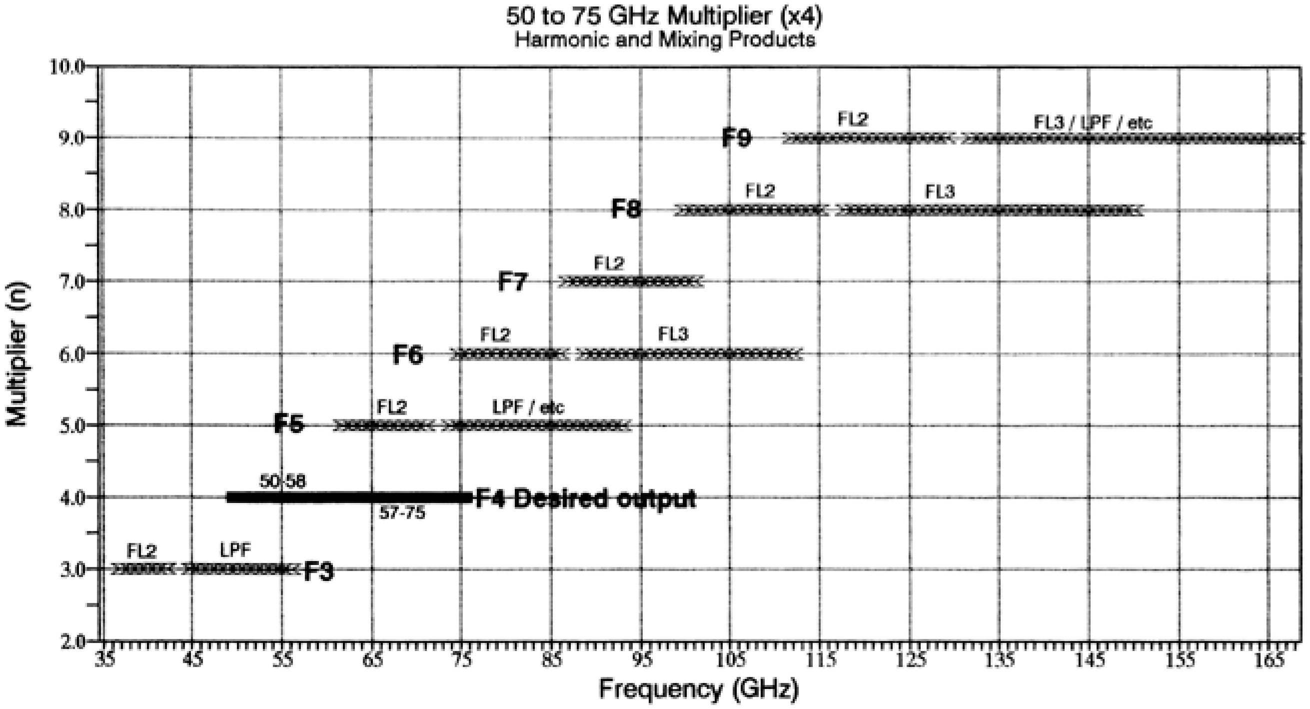
The Effects of other Spurious and Harmonics

The 3/2 harmonic could have been suppressed with a much wider bandwidth filter, i.e. 50 to 70 GHz, but other spurious signals would still impact our scalar analysis capability. The segmenting of the band and use of bandpass filters FL2 and FL3, along with other filtering devices, have been combined to address these additional sources of spurious and harmonic energies. Multipliers, as non linear circuits, produce higher order harmonics (as well as fundamental feedthrough) and mixing products (spurious signals). The final output multiplier generates harmful 3rd and 4th harmonics that can be detected by the systems detectors. In addition, the third harmonic of the intermediate doubler/driver amplifier can mix in the final multiplier with the desired drive signal or one of the higher order harmonics generated by the final multiplier to produce signals that would be detectable by the system's detectors. The band segments described above were chosen to separate these undesired signals so that the FL2 and FL3 band pass filters, a specially designed 3rd harmonic band reject filterfor the doubler/driver amp, and other filtering devices, **suppress all spurious and harmonic products to greater than -50 dBc.**

Each OML reflectometer is supplied with both of the bandpass filters, FL2 and FL3, and a full band straight through section, FL1, for use when full band performance is needed and undesired signal suppression can be sacrificed. ***The band of operation must be limited to the filter bandwidths to achieve best spurious suppression.*** The information contained in Tables 1 and 2 examines the most troublesome of these harmonic and mixing products and describes the circuit elements used to suppress them.

A final item of caution is necessary. Anytime a multiplier is being used, any harmonic or spurious outputs of the driving source, i.e. the microwave sweep generator, will be translated to the final frequency to some degree. The out-of-band harmonics of these microwave sources are generally suppressed by the lowpass and other filters in the OML multiplier chains. However, some sweep generators themselves use multipliers or mixers to achieve the 12.5 to 18.75 GHz coverage that is used to drive the reflectometers. To ensure the best possible millimeter wave scalar analysis dynamic range, the user should check the sweep generator that will be used, for these harmful products in its output content. For optimim performance it is suggested that the user utilize only fundamental oscillator sweep generators for configuring the millimeter scalar analysis system.

Table 1



F1 The 12.5 to 18.75 GHz, input signal.

F2 The output of the doubler/amplifier (driver), 25 to 37.5 GHz.

F3 The driver produces a third harmonic output that is -20 dBc. The roll off of the driver's output hybrid limits the undesired signal to 37.5 to 43.5 GHz. When sweeping 50 to 58 GHz, this spur covers 37.5 to 43.5 GHz and is suppressed by the band pass filter (BPF) FL2 and the output waveguide (WR-15 cutoff is at 40 GHz). When sweeping 57 to 75 GHz, this spur covers 42.75 to 56 GHz, which is suppressed by the roll off of the driver's output hybrid and the doubler's input LPF. In both cases the suppression exceeds 50 dB

F6 {F2x3} This is the third harmonic of the doubler input signal covering 75 to 112.5 GHz. and is a natural, though undesired, output of the doubler. It is typically suppressed 20 dB in the doubler and is further suppressed to <-50 dBc through the use of either BPF FL2 or FL3.

F7 {F4+F3} This 87.5 to 101.5 GHz product is created in the doubler by the mixing the desired F4 output signal with the driver's third harmonic (37.5 to 43.5 GHz, see F3 explanation). This product appears only when sweeping the 50 to 58 GHz band segment. The use of FL2 serves to suppress this undesired signal to <-50 dBc.

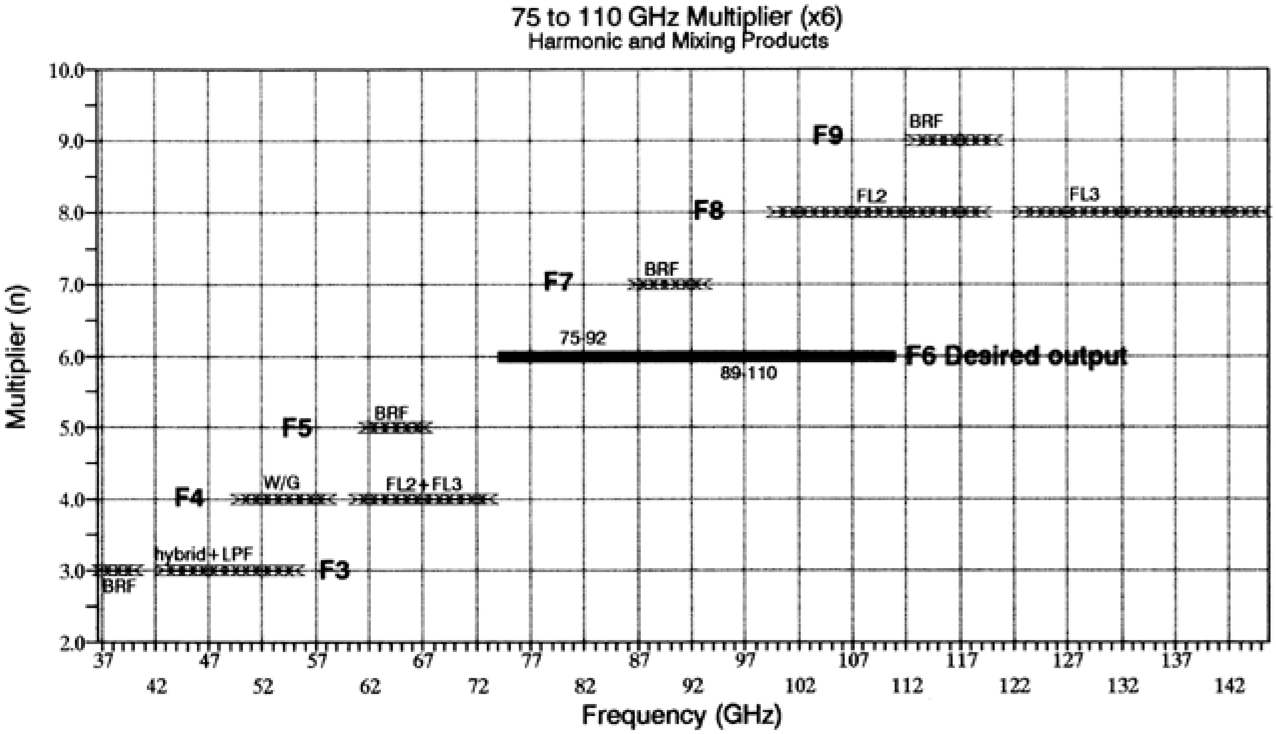
F4 The desired "doubler" output, 50 to 75 GHz. 50 to 58 GHz w/FL2 57 to 75 GHz w/FL3

F5 {F3+F2} This is the most troublesome undesired spurious produced. It is created by the mixing of the desired high level driver signal (F2) with undesired driver 3rd harmonic (F3) in the doubler (see F3 above). When sweeping 50 to 58 GHz, the spurious produced covers 62.5 to 72.5 GHz. These signals are suppressed by FL2 to <-50 dBc. The spurious product created when sweeping 57 to 75 GHz would cover 71.25 to 93.75 GHz. The roll off of the driver's output hybrid, the doubler's input LPF, and the isolation provided by the doubler (when acting as a mixer) limits the production of this spurious product to a level no higher than -50 dBc.

F8 {F2x4} The fourth harmonic of the doubler input signal. This 100 to 150 GHz product is a natural, though undesired, output of the doubler. It is typically suppressed in the doubler to approximately -20 dBc. This product is then suppressed to <-50 dBc through the use of either FL2 or FL3. Any higher mode BPF leakage is undetectable by the reflectometers detectors.

F9 {F4+(F3+F2)} This product is created in the doubler by the mixing the desired F4 output signal with another doubler mixing product, F3+F2 (see the previous F3+F2 explanation). This product covers 112.5 to 168.75 GHz and occurs due to the high level of F4 acting as the pump for the mixing process. This product is suppressed to <-50 dBc through the use of either FL2 or FL3. Any higher mode BPF leakage is undetectable by the reflectometers detectors.

Table 2



F1 The 12.5 to 18.33 GHz, input signal.

F2 The output of the doubler/amplifier (driver), 25 to 36.33 GHz.

F3 Harmonic The driver third harmonic which is -20 dBc. For the 75 to 92 GHz band, this harmonic covers 37.5 to 46 GHz. The frequency response of the driver's output hybrid limits the undesired signal to 37.5 to 40 GHz. A band reject filter (BRF), between the driver and the tripler, suppresses the undesired 37.5 to 40 GHz energy. For outputs in the 89 to 110 GHz band, the harmonic is already suppressed by the driver output hybrid roll-off and is further suppressed by the tripler's input low pass filter (LPF). In all cases the suppression exceeds 50 dB.

F5 {F2x2+(F3-F2)} See F3, "Mixing product." This spurious (62.5 to 66.6 GHz) is the upper sideband of the process described in "F3 mixing." This product is prevented by the 37.5 to 40 GHz band reject filter.

F6 The desired tripler output, 75 to 110 GHz. 75 to 92 GHz w/FL2 89 to 110 GHz w/FL3

F7 {F2x4-(F3-F2)} See F3, "Mixing product." This spurious (87.5 to 93.3 GHz) is a further result of the mixing process. It is the lower sideband of mixing of F3 and the 4th harmonic (F4) of the driver signal. This product is prevented by the 37.5 to 40 GHz band reject filter.

F3 Mixing Product {F2x2-(F3-F2)} This is a tripler mixing product. The driver output signal, 25 to 26.7 GHz, and associated undesired third harmonic (37.5 to 40 GHz) mix to produce a 12.5 to 13.3 GHz lower sideband. This sideband can not propagate through any of the waveguides, but is present at the tripler diodes. This sideband mixes with the 2nd harmonic of the driver signal (50 to 53.3 GHz) to produce 37.5 to 40 GHz. The above and other mixing products are prevented by the 37.5 to 40 GHz BRF.

F4 {F2x2} The second harmonic of the tripler input signal (50 to 72.6 GHz). This harmonic is suppressed to -20 dBc by the tripler. The WR-10 waveguide (W/G) cutoff completely suppresses the signal below 59 GHz. Above 59 GHz, this product is suppressed by the bandpass filters (BPF) FL2 or FL3.

F8 {F2x4} The fourth harmonic of the tripler drive signal (100 to 145 GHz). This is a natural, though undesired, -20 dBc output of the tripler. The BPF's, FL2 or FL3 are used to suppress the harmonic level to less than -50 dBc.

F9 {F3x3} The third harmonic output of the driver is also tripled by the tripler (-20 dBc). The roll-off of the unit's hybrid limits the undesired output to 112.5 to 120 GHz. The 37.5 to 40 GHz BRF suppression effectively eliminates this problem.

F9 {F2x4+(F3-F2)} See F3, "Mixing product." This spurious (112.5 to 120 GHz) is the upper sideband product of mixing F3 and the 4th harmonic (F4) of the driver signal. This product is prevented by the 37.5 to 40 GHz BRF.

Noise Performance and FM

The OML reflectometer sources provide excellent residual (or added) phase noise performance. This is due to the balanced diode rectifier type circuit used in the doublers and triplers of the OML sources. The residual noise product of this type of multiplier is insensitive to input power variation. Compared to step recovery diode or varactor diode multipliers, which go through "noisy" degenerative states when the input power is varied, the balanced rectifier type multiplier residual phase noise does not significantly change with input power changes. The drive frequency, when so multiplied, is subject to phase noise degradation equal to 20 log N (dB) (N being the multiplication factor) plus an approximate 1 dB additional degradation contributed by the diode's 1/F noise, etc.. The noise degradation experienced when using a V Band reflectometer (a doubler/doubler) is typically less than 14 dB. The degradation of the W Band reflectometer multiplier (a doubler/tripler) will be approximately 17 dB.

The reflectometer sources will reproduce any frequency modulation present on the drive signal. However, the frequency deviation of the drive signal is factored by the multiplication ratio. If frequency modulated operation is desired, this factoring needs to be accounted for by adjusting the drive signal deviation to achieve the desired output characteristic.

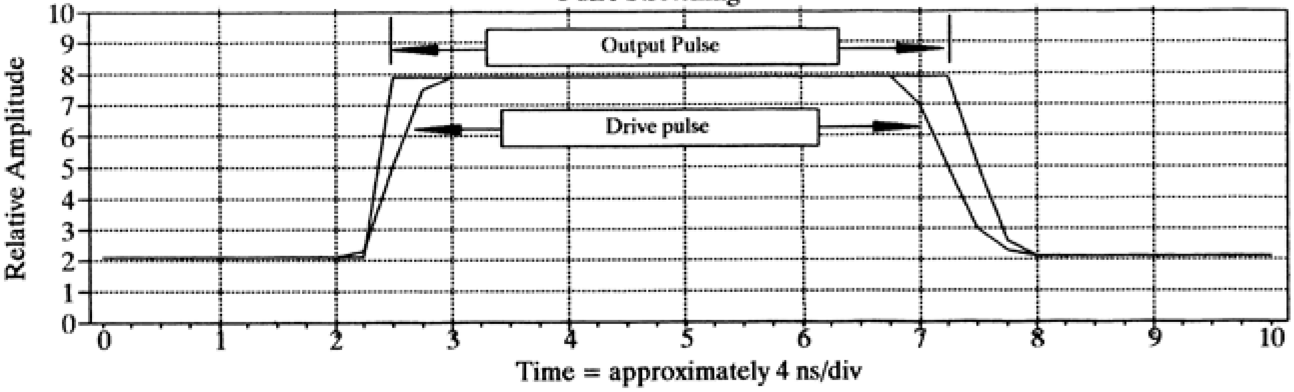
Pulse Performance

The filters, amplifiers, isolators, and multipliers used in the reflectometers are all low "Q" devices and do not measurably contribute to degradation of an input signal's pulse characteristics. In fact, the multipliers will measurably improve the rise time of a pulse. This is caused by the transfer characteristic of the multipliers. At low input signal levels (below -20 dBm) the multiplier output will increase at a rate close to 2:1 for each dB of drive power increase. As the diode's "knee" is approached the rate of change goes through a transitional phase. Once the diodes are fully turned "on" the input to output ratio is 1:1 up to the beginning of compression. It can be seen that the rate of rise on the leading edge of the output pulse will actually be faster than that of the drive pulse. The reciprocal is true on the falling edge of the output pulse with the first half of the fall time being slower than the second half.

This understanding of the above rise and fall behavior is complicated by the presence of the driver amplifier needed to boost the signal to a level to efficiently drive the final multiplier. If the user needs flat power performance (+/- 4 dB or better) it is necessary to not only operate the multiplier in compression, but also to operate its driver amplifier in saturation (it is easier to saturate the wide band amplifier than the multiplier). The saturation (or at least deep compression) of the amplifier, will cause stretching of the output pulsewidth, as illustrated on the next page. This stretching occurs during both the rise and fall of the pulse. It is caused by the rise time acceleration resulting from the amplifier entering the saturation portion of the transfer characteristic and the time it takes for the amplifier to drop out of saturation into the linear region when the drive signal starts to fall. Figure 4 illustrates the combined effects of the multiplier and the saturated amplifier on pulse width. There is then, a direct trade-off between power flatness and the fidelity of the pulse replication. This trade-off involves, to a minor degree, rise and fall time performance, and to a large degree, pulse width fidelity. The OML reflectometers are engineered to achieve a balance between power flatness and pulse fidelity.

The pulse performance described above does not impact the operation of the OML scalar system when used with AM (actually pulse) modulated scalar systems produced by some manufacturers. The on/off ratio of the modulation when viewed at the OML reflectometer test port is actually superior to that of the microwave sweep generator output due to the processes described above. If those manufacturers had used a synchronized detection scheme, the OML on/off ratio would actually be a benefit. The OML reflectometer pulse performance does not improve or degrade their system performance.

Figure 4 Amplifier/Multiplier
Pulse Stretching



OML Directional Couplers

The OML reflectometer utilizes an OML designed and manufactured dual directional coupler. The coupler is a split block design with no physical or electrical overlap of the coupled arms. This serves to ensure a high degree of isolation between the reference and reflection detector circuits. The coupler was also designed to use the fewest parts possible (fewer joints) so as to eliminate as much waveguide field leakage (and accompanying insertion loss) as possible. The coupler directivity achieved is typically greater than 40 dB at the worst point in the band. This performance was verified for both V and W Bands with data taken on a Wiltron 360B Vector Analyzer Millimeter System. OML measures directivity by use of the "broken load" technique developed by the TRW Metrology Lab and others. In the OML measurement procedure, the system is calibrated by placing a waveguide short at the reflectometer output port. The reflection data is used to calibrate the scalar analyzer using the "transmission" routine. Because waveguide is dispersive and the results are entirely different than in coax, the "short/open" or "short/offset short" "reflection" calibration routine cannot be used. An unmounted load is then inserted into the reflectometer waveguide output port. The position of the load is adjusted through two reflection null cycles, looking to achieve the best full band reflection pattern as detected by the reflection detector. The load is adjusted to best terminate all phases of energy in this manner. The largest peak detected is assumed to be the worst case limit of the coupler's directivity. It is believed that this measurement technique is relatively conservative, primarily due to the limited return loss of available loads.

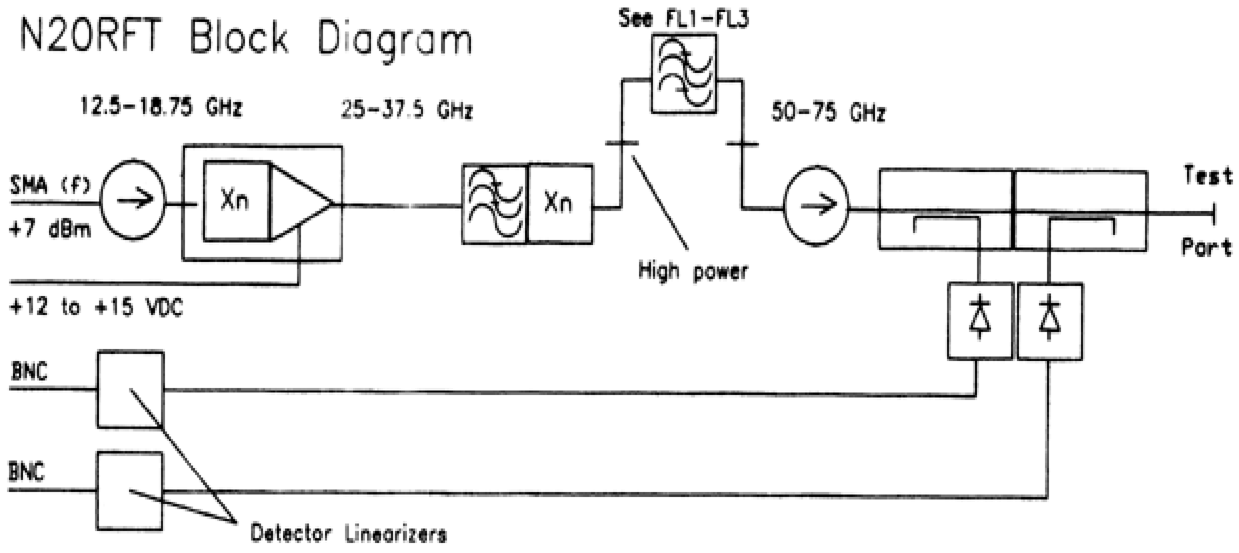
The OML coupler exhibits a 9 dB nominal coupling factor and is flat +/- 1 dB across the entire band. Because of the low field leakage design, the coupler exhibits very low insertion loss which enhances the source match characteristic of the reflectometer.

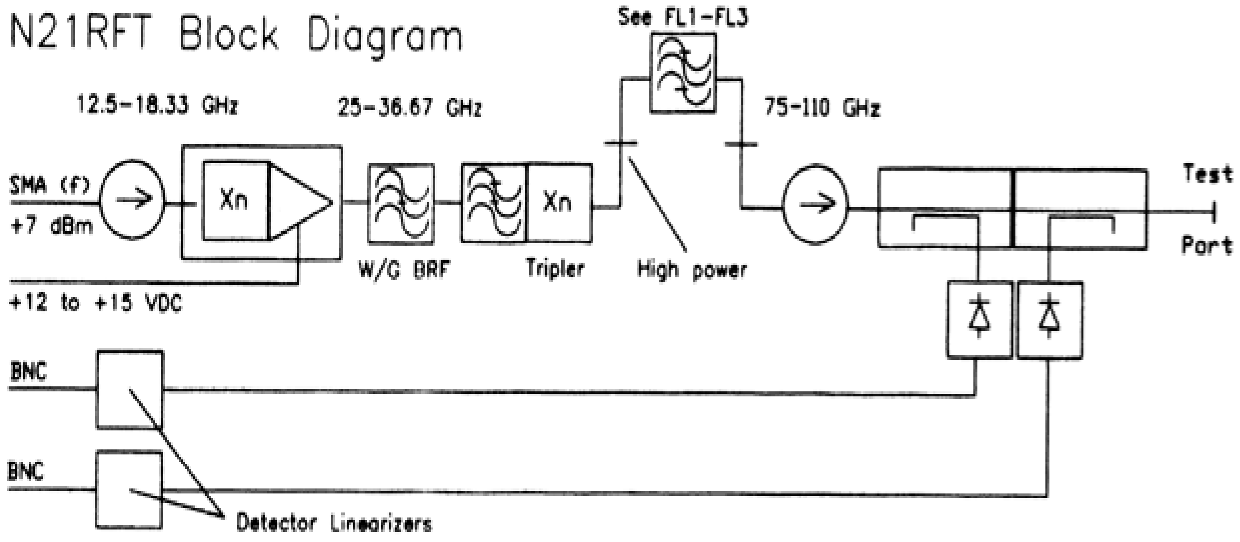
Waveguide Detectors

Each detector used in the OML scalar analysis system contains two detector diodes that are hybrid coupled to the waveguide input. This configuration achieves a detector return loss of typically 10 dB. The minimum sensitivity of the 50 to 75 detector is 450 mV/mW, and the minimum 75 to 110 GHz detector sensitivity is 250 mV/mW. An isolator has been incorporated into the detector unit to improve detector return loss and improve the frequency response. These improvements more than offset the resulting decrease in sensitivity. The typical detector achieves >18 dB return loss in V Band and >17 dB return loss in W Band. All detectors are provided with linearizing circuits and come pre-adjusted for best performance. The user must supply the appropriate interface adapter/cables for his scalar analysis system. These detectors are compatible with the HP DC detector adapters and all other manufacturer's systems that have been tested as of this writing (see list). Note: The above detector sensitivities are measured into a 1 megohm load and are measured in the square law region.

Cost effective millimeter capability

The OML reflectometer system offers engineers and technicians the ability to expand on their existing microwave test equipment and achieve high performance millimeter capability. As previously stated, the reflectometers can be driven by any sweep generator or signal generator capable of +7 dBm output (nominal) over the appropriate frequency range (12.5 to 18.75 GHz). This eliminates the need for an expensive outboard driver amplifier or special sweeper plug-in. An additional 3 to 4 dB of power is available to the user at the output of the multiplier. The Rhodium plated waveguide flange, where the "FL" filters connect, is the access to this higher power. The signal will not be filtered or isolated at that point. If the driving source has the capability of having frequency offsets or multiplication factors applied to its frequency readout (most late model systems do), scalar analysis can be achieved with correct frequency annotations on the CRT and output plot. The small size of the reflectometer and limited number of necessary interfaces help simplify the test bench setup. The reflectometers are available with optional power supplies, approved by the country of intended use (this approval was received by the power supply manufacturer, not OML) or can be operated with any available +12 to 15 volt power supply of the proper DC current capability. Some analyzers have the necessary current supply capability at an accessory port (check the system manual).


N20RFT Block Diagram
See FL1-FL3
12.5-18.75 GHz
25-37.5 GHz
50-75 GHz
SMA (f)
+7 dBm
Xn
Xn
Test
Port
High power
+12 to +15 VDC
BNC
BNC
Detector Linearizers


N21RFT Block Diagram
See FL1-FL3
12.5-18.33 GHz
25-36.67 GHz
75-110 GHz
SMA (f)
+7 dBm
Xn
Xn
Test
Port
W/G BRF
Tripler
High power
+12 to +15 VDC
BNC
BNC
Detector Linearizers

Reflectometer Specifications:	**N20RFT**	**N21RFT**
Frequency Range FL1 installed FL2 installed FL3 installed	 50 to 75 GHz 50 to 58 GHz 57 to 75 GHz	 75 to 110 GHz 75 to 92 GHz 89 to 110 GHz
Waveguide Interface Compatibility	Mil.-F-3922/67B-008 Flange	Mil.-F-3922/67B-010 Flange
Reflectometer Output Power	0 dBm min. w/FL1 +5 dBm typical	-5 dBm min. w/FL1 2 dBm typical
Source Spurs and Harmonics	-20 dBc typ. w/FL1 -50 dBc max. w/FL2 or FL3	-20 dBc typ. w/FL1 -50 dBc max. w/FL2 or FL3
Reflectometer Output Match	18 dB typ	18 dB typ.
Reflectometer Coupler Directivity	35 dB min. 40 dB typ.	35 dB min. 40 dB typ.
Source Input Frequency	12.5 to 18.75 GHz	12.5 to 18.333 GHz
Required Input Power	+7 dBm	+7 dBm
Source Input Return Loss	17 dB typ.	17 dB typ.
Source Input Connector	"SMA" (f)	"SMA" (f)
Detector Output Connectors	"BNC" (f)	"BNC" (f)
Size (LxWxH)	8.7 x 4.25 x 2.25 inches	7.5 x 4.25 x 2.25 inches
Scalar System Compatibility	Most scalar analyzers with the appropriate adapters	
Voltage/Current Required	+12 VDC @ 750 mA. max. (will operate up to +15 VDC)	
Accessories:	Calibration Short and 1" waveguide section supplied. Different band pass filters (optional)	

Transmission Detector Specs:	**N20DET**	**N21DET**
Frequency Range	50 to 75 GHz	75 to 110 GHz
Waveguide Interface Compatibility	Mil. -F-3922/67B-080 Flange	Mil. -F-3922/67B-010 Flange
Detector return Loss	20 dB typ.	19 dB typ.
Detector Flatness	+/- 3 dB	+/- 3 dB
Detector Output	250mV/mW typ.	150 mV/mW typ.
CW Input Power	100 mW max.	100 mW max.
Detector Output Connector	"BNC" (f)	"BNC" (f)
Scalar System Compatibility	Most scalar analyzers with the appropriate adapter	

The OML N20RFT and N21RFT Reflectometer Systems have been successfully used to extend the frequency coverage of the following 12.5 to 18.75 GHz scalar analysis systems:

Scalar Analyzer/Microwave Sweeper	**Scalar Analyzer/Microwave Sweeper**
Giga-tronics 8003 / 910	PM 1038 N10 / Wiltron 6600A/B series
Giga-tronics 8003 / 9000 series	PM 1038 N10 / HP 8350 A/B
HP 8755C / HP 8350A/B	PM 1038 N10 / Marconi 8910/11
HP 8756A / HP 8350A/B	Wiltron 560A / 6600A/B / 6700A/B series
HP 8757A-E / HP 8350A/B	Wiltron 561 / 6600A/B / 6700A/B series
HP 8757A-E / HP 8340/41	Wiltron 5400 series
HP 8757A-E / 83751/2A/B	Wiltron 54100 series
HP 8757A-E / 8360 Family	Wiltron 562 / HP 8350B
Marconi 6200	Wiltron 562 / 6600A/B 6700A/B series
PM 1038 N20	Wiltron 562 / 68100 series

Each of the above systems requires an appropriate adapter cable to interface with the OML millimeter wave detectors. Consult the scalar analyzer owner's manual for the appropriate adapter cable part number. The OML scalar analysis systems come with pre-adjusted linearizers for the detector outputs. The customer is responsibile for adjusting HP adapters if used. Gigatronics adapters designed for use with third party detectors may not be compatible with the OML detectors.