Application Note 3340-001

Use of the TSI LAS Model 3340 for HEPA Filter Testing

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Basic Setup for Filter Testing

Measuring filter efficiency always follows the same scheme: A test aerosol is fed into a test duct upstream of the filter under test. Particle concentration measurements are then taken upstream and downstream of this filter. Either one particle measuring system [e.g., Scanning Mobility Particle Sizer™ (SMPS™) spectrometer, Laser Aerosol Spectrometer, Aerodynamic Particle Sizer® (APS™) spectrometer] or two parallel instruments of the same kind may be used for the measurement. In case only one instrument is used, up- and downstream measurements can be made either without or with the filter in place, respectively, or a sample flow switching valve can be used to connect the single instrument to an upstream and downstream sampling port.

For most filters, the particle concentration on the upstream side must be quite high to allow reasonably short measurement time on the downstream (clean) side. Therefore, the upstream sample must be diluted before it enters the particle instrument for measurement. In addition to the particle measurement, the measurement of pressure, temperature, relative humidity, filter flow rate and filter resistance (pressure drop) are common for a complete filter test.

For most filter tests, industry standards or regulations apply which define the test aerosol (size range and particle material), the type of particle instrument to be used [Airborne Particle Counter (APC), Aerodynamic Particle Sizer® (APS™) spectrometer, Condensation Particle Counter, Condensation Particle Counter plus Differential Mobility Analyzer, Scanning Mobility Particle Sizer™ (SMPS™) spectrometer, photometer, etc.), the size classes in which the filter penetration or efficiency shall be reported, and the test procedure itself. Figure 1 shows the schematic setup of a filter test.

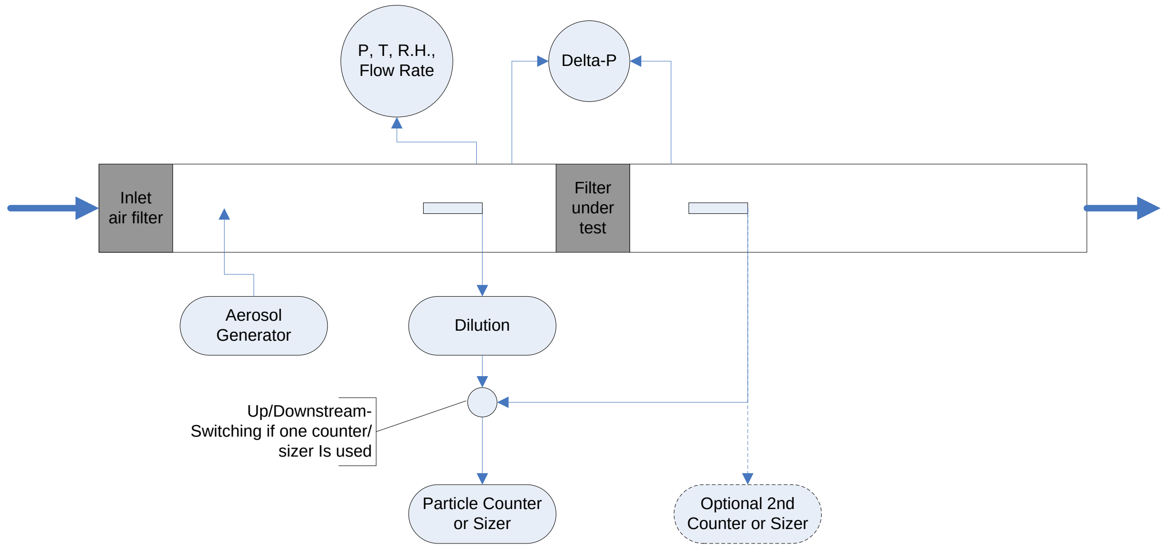


Figure 1: Schematic Filter Test Setup

Methods for HEPA & ULPA Filter Testing Available from TSI

Table 1: Overview Over Test Methods Applicable for HEPA and ULPA Filter Media And Filters

Method	Description	Advantage	Disadvantage
Monodisperse test aerosol (from DMA), measurement with one or two CPC(s)	e.g., AFT 3160 Monodisperse aerosol from DMA counted by CPC upstream and downstream	• Size range 20 nm to 800 nm applicable for electret filters and glass fiber filters. • Low upstream dilution 100:1 can be verified/calibrated in situ. • Software available (CERTITEST® Model 3160)	• One measurement per size (time consuming) • Only applicable for low flow rates <100 L/min (e.g., filter media and cartridges)
Polydisperse test aerosol and sampling through DMA to CPC	Aerosol generator (8130 oil generator or 9306A) feeds into test duct, CPC samples known size through DMA	• Size range 20 nm to 800 nm applicable for electret filters and glass fiber filters. • Low upstream dilution 100:1 can be verified/calibrated in situ. Software available (CERTITEST® 3160 special) • Works with high flow rates up to 300 m³/h. Above this, more than one generator (parallel) necessary.	• Low downstream concentration after DMA requires long sampling time. • Filter loading effects can bias measurement. • Separate upstream and downstream measurement (also time consuming) or two DMAs and CPCs (expensive) necessary.
Polydisperse test aerosol and LAS 3340	Aerosol generator (8130 oil generator or 9306A) feeds into test duct, LAS measures upstream and downstream size distribution	• Simultaneous measurement of all sizes reduces necessary measurement time. • Method works for low flow (filter media) and high flow applications.	• High upstream dilution 1000:1 to 10000:1 cannot be verified/calibrated in situ. • Size range (>90 nm) limits this method to glass fiber HEPA/ULPA filters

All methods listed in Table 1 can be realized using TSI equipment. The size range from 0.09 µm to 7.5 µm makes the Laser Aerosol Spectrometer LAS 3340 a very interesting instrument for air filter testing. Especially for glass fiber HEPA and ULPA filters (most penetrating particle size MPPS between 100 nm and 200 nm), but also for HVAC filters, the instrument offers advantages.

- Simultaneous measurement of all particle sizes can reduce the necessary measurement time.

- With a well adapted aerosol generator, measurements can be applied for filter media (low flow rate), filter cartridges (medium flow rate) and filter panels (high flow rate).

However, the requirements in filter testing may be challenging, which often makes optimization of test aerosol concentration, upstream dilution, used size resolution and downstream sampling time necessary. Figure 2 demonstrates how the parameters characterizing a filter test are linked to each other.

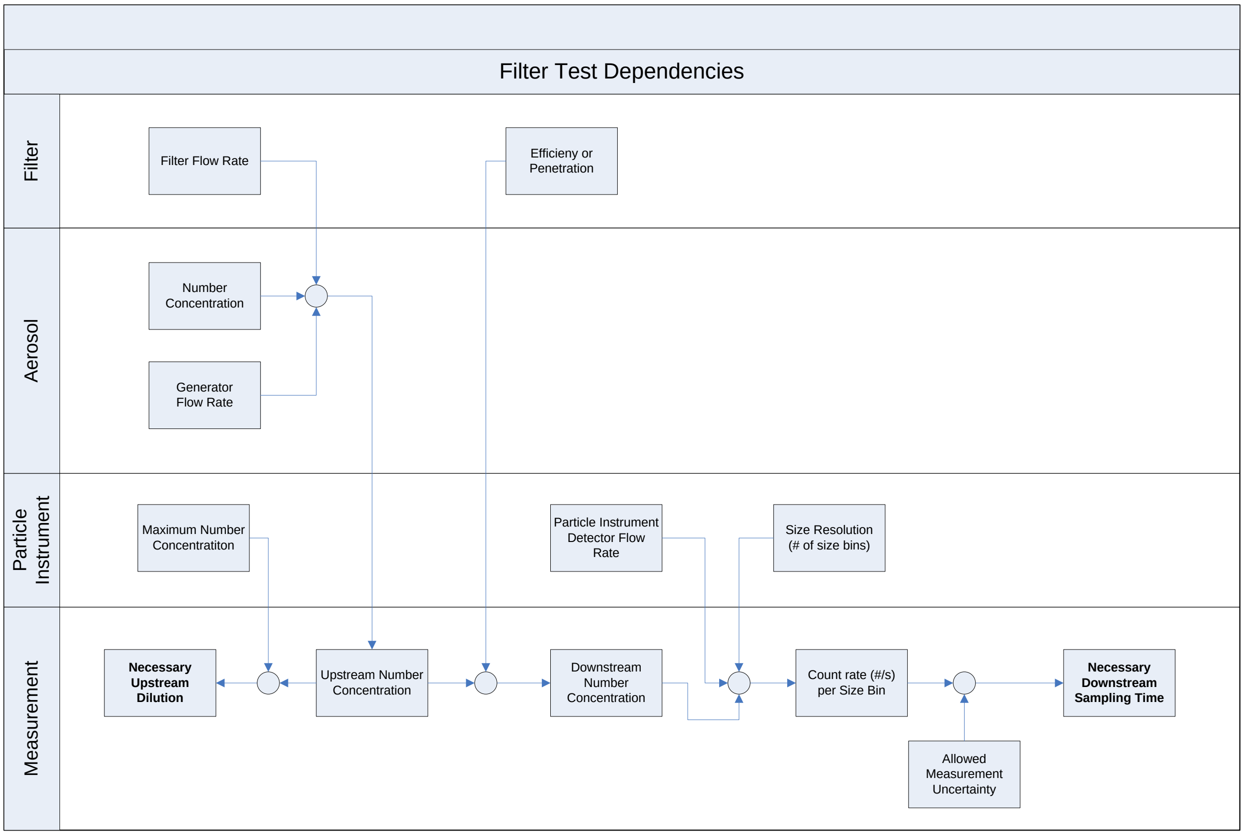


Figure 2

The most critical parameter in filter testing is the number of particles counted in each size bin on the downstream side of the filter. The more particles counted, the lower the measurement uncertainty, see section on counting statistics. For a given uncertainty requirement (equals total number of particles counted in a size bin), the downstream count rate for each size bin determines the necessary sampling time. If, for example, the downstream sampling time shall be shortened, this can be achieved in several ways:

- The aerosol generator output (#/s) can be increased, which then increases both the upstream and downstream number concentration and therefore the downstream count rate. It is important to check if the upstream dilution must be increased as well in order to keep the upstream particle concentration within the specification of the LAS.
- The detector flow rate of the LAS can be increased (if possible).
- The number of size bins can be reduced, thus making the size bins wider (result: more particles counted in each bin). This can either be done in the instrument configuration or by post processing (see measurement example).
- Last but not least, a higher measurement uncertainty could be accepted if this is allowed (reduce the necessary number of particles counted in the size bins).

As already explained above, it is also very important to dilute the upstream particle concentration for the measurement: The LAS 3340 allows a maximum particle count rate of 3000 particles per second (with

5% coincidence error). This corresponds to 1800 #/cm³ at maximum flow rate, 3600 #/cm³ at 50 cm³/min and 18000 #/cm³ at 10 cm³/min, respectively.

Measurement Uncertainty and Counting Statistics

Detecting particles in a single particle measuring instrument like the LAS 3340 is a statistical process, simply because the particles do not appear in the detector evenly distributed over time. If, over the measurement time period, a certain number of particles have been counted, this number is directly linked to uncertainty via Poisson statistics. The uncertainty is usually described by means of the 95% confidence interval. If, for example, 1000 particles have been accumulated in a size bin during the measurement, there is a 5 % uncertainty (or: there is 95 % confidence) that the true number concentration, which would be found by infinite counting, is between 938 and 1062. This range is called the 95% confidence interval.

If the number of counted particles N is larger than 100, the lower and upper boundary of the 95% confidence interval can be calculated using

$$N_{\pm 95\%} = N \pm 1.962 \cdot \sqrt{N} \tag{1}$$

In this case, the relative uncertainty U in the measurement is

$$U_{\pm 95\%}[\%] = 100\% \cdot \frac{N_{\pm 95\%} - N}{N} = \pm 100\% \cdot \frac{1.962 \cdot \sqrt{N}}{N} \tag{2}$$

This means that the statistical uncertainty for 1000 counted particles is ±6.2 %.

Inverting equation 2 leads to the necessary particle counts N_i in a size bin for an allowed uncertainty U:

$$N_i(U) = \left(1.962 \cdot \frac{100\%}{U}\right)^2 \tag{3}$$

For example, 1537 particles must be counted to reach ±5% uncertainty or 384 particles must be counted to reach ±10% uncertainty, respectively.

Filter Measurement Example

This example shows results from the measurement of a HEPA filter; the following parameters characterize the measurement:

Parameter	Value
Filter type	HEPA, H14 according to EN1822
Filter flow rate	300 m³/h (5000 l/min)
Test aerosol	Paraffin Oil, D50 ≈ 200 nm, GSD ≈ 1.9
Upstream number concentration	2.4E6 P/cm³
Upstream dilution	1000:1
Particle instrument	TSI LAS Model 3340
Flow rate for upstream measurement	39.8 cm³/min
Flow rate for downstream measurement	99.2 cm³/min
Selected size range	90 nm to 1000 nm
Selected number of size bins	30
Selected sampling time	5 x 2 min on each filter side

Results:

With above parameters, five measurement runs on both the upstream and downstream side were made. To reduce the downstream measurement uncertainty, three adjacent size bins were combined into one new size bin when post-processing the data. The data shown below are based on two minute measurements.

The 95% confidence value for the penetration was then calculated by using the lower limit of the 95% confidence interval for the upstream counts and the upper limit of the 95% confidence interval for the downstream counts.

UPSTREAM

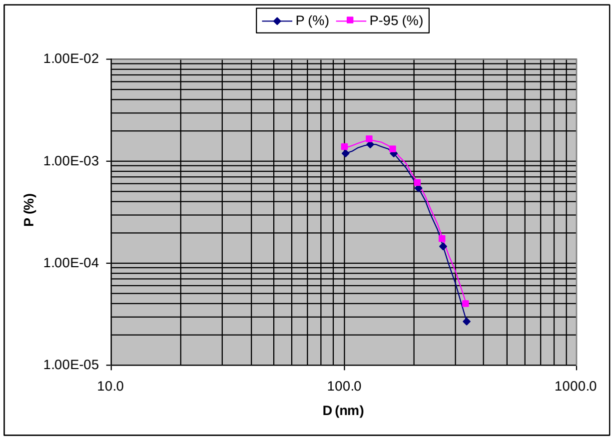
Diameter (nm)	101.5	129.2	164.3	209.1	266.0	338.4
Counts in 2 min	11301	19072	29138	35005	35290	27801
Counts 95% min	11092.6	18801.7	28803.2	34637.9	34921.8	27473.8
Concentration (1/cm³)	1.42E+05	2.40E+05	3.66E+05	4.40E+05	4.43E+05	3.49E+05
Concentration min (1/cm³)	**1.39E+05**	**2.36E+05**	**3.62E+05**	**4.35E+05**	**4.39E+05**	**3.45E+05**

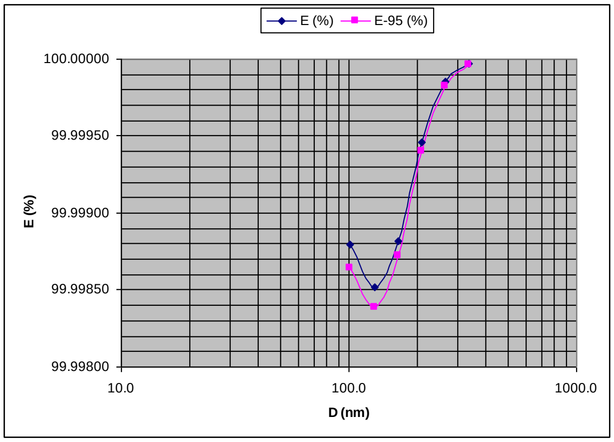
DOWNSTREAM

Diameter (nm)	101.5	129.2	164.3	209.1	266.0	338.4
Counts in 2 min	339	703	857	473	127	18
Counts 95% max	374.9	755.0	914.8	515.2	149.5	26.8
Concentration (1/cm³)	1.71E+00	3.54E+00	4.32E+00	2.38E+00	6.42E-01	9.27E-02
Concentration max (1/cm³)	**1.89E+00**	**3.80E+00**	**4.61E+00**	**2.60E+00**	**7.54E-01**	**1.35E-01**

PENETRATION & EFFICIENCY

D (nm)	**101.5**	**129.2**	**164.3**	**209.1**	**266.0**	**338.4**
P (%)	1.20E-03	1.48E-03	1.18E-03	5.42E-04	1.45E-04	2.66E-05
P-95 (%)	**1.36E-03**	**1.61E-03**	**1.27E-03**	**5.97E-04**	**1.72E-04**	**3.92E-05**
E (%)	99.99880	99.99852	99.99882	99.99946	99.99986	99.99997
E-95 (%)	**99.99864**	**99.99839**	**99.99873**	**99.99940**	**99.99983**	**99.99996**





Alternatively, it would have been possible to add all five measurements, which then corresponds to a 10 minute measurement on each side of the filter. This further reduces the measurement uncertainty, as can be seen in the following data:

UPSTREAM

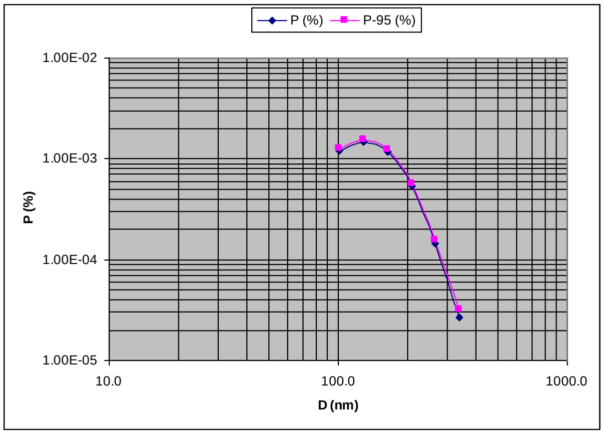
Diameter (nm)	101.5	129.2	164.3	209.1	266.0	338.4
Counts in 10 min	56505	95362	145689	175023	176450	139003
Counts 95% min	56039.1	94756.7	144940.9	174203.0	175626.7	138272.3
Concentration (1/cm³)	1.42E+05	2.40E+05	3.66E+05	4.40E+05	4.43E+05	3.49E+05
Concentration min (1/cm³)	**1.41E+05**	**2.38E+05**	**3.64E+05**	**4.38E+05**	**4.41E+05**	**3.47E+05**

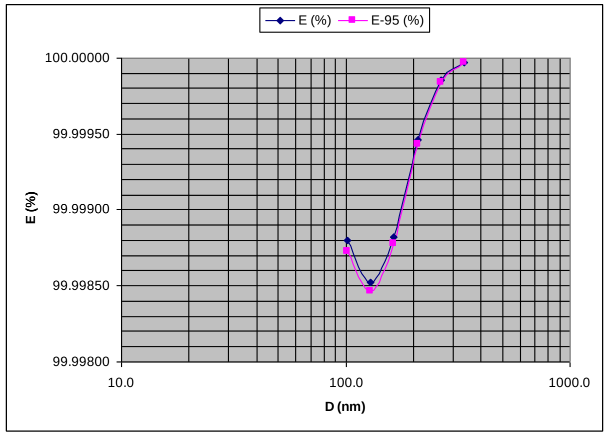
DOWNSTREAM

Diameter (nm)	101.5	129.2	164.3	209.1	266.0	338.4
Counts in 10 min	1694	3515	4287	2363	637	92
Counts 95% max	1774.7	3631.2	4415.3	2458.3	686.5	110.8
Concentration (1/cm³)	1.71E+00	3.54E+00	4.32E+00	2.38E+00	6.42E-01	9.27E-02
Concentration max (1/cm³)	**1.79E+00**	**3.66E+00**	**4.45E+00**	**2.48E+00**	**6.92E-01**	**1.12E-01**

PENETRATION & EFFICIENCY

D (nm)	**101.5**	**129.2**	**164.3**	**209.1**	**266.0**	**338.4**
P (%)	1.20E-03	1.48E-03	1.18E-03	5.42E-04	1.45E-04	2.66E-05
P-95 (%)	**1.27E-03**	**1.54E-03**	**1.22E-03**	**5.66E-04**	**1.57E-04**	**3.22E-05**
E (%)	99.99880	99.99852	99.99882	99.99946	99.99986	99.99997
E-95 (%)	**99.99873**	**99.99846**	**99.99878**	**99.99943**	**99.99984**	**99.99997**





Reducing Sampling Losses

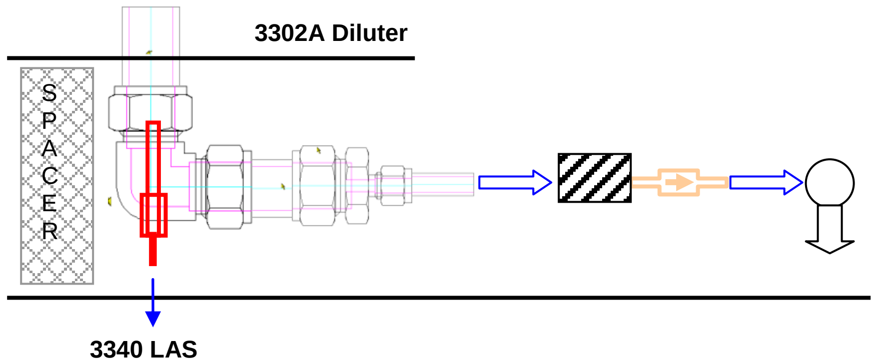
Particle losses in the sampling line from the instrument to the sampling ports on the test bench may bias the measurements. To overcome this problem, tubing of equal length (or better: the same tubing) should be used to connect to both the upstream and the downstream sampling port. While this will minimize the differences between upstream and downstream particle loss, the losses themselves might still be significant, which unnecessarily reduces especially the downstream particle counts and results in increased measurement uncertainty.

The sampling losses can be reduced by several means:

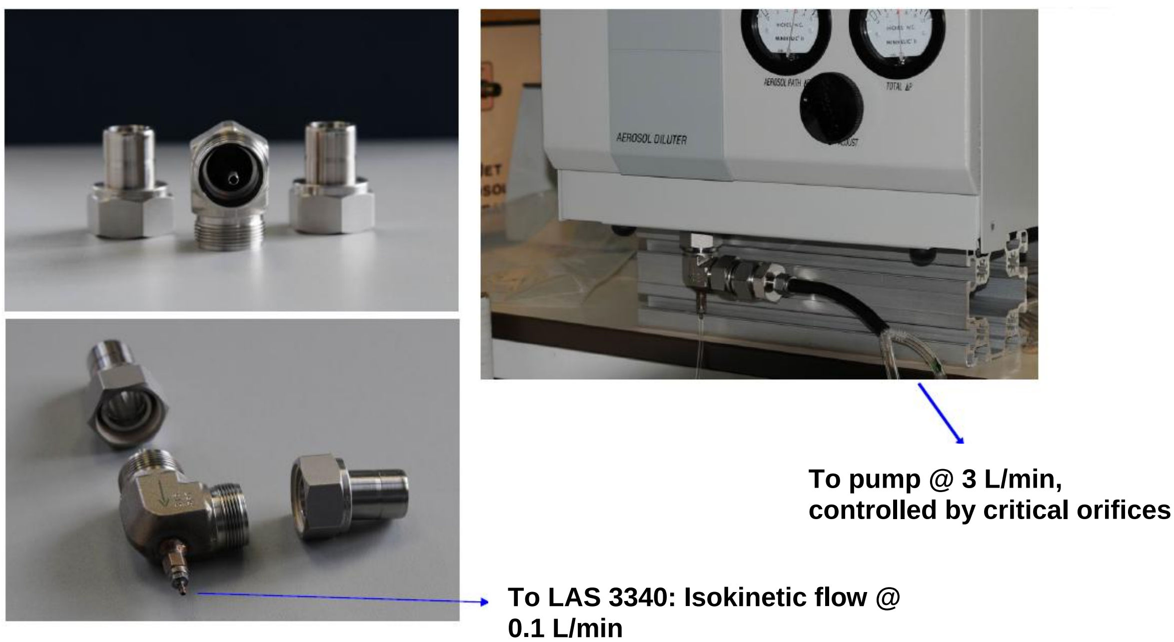
- Keep sampling tubing as short as possible.
- Use either conductive flexible tubing or stainless steel tubing
- Increase the sampling flow rate, but keep the flow laminar (recommendation: $1000 < Re < 1500$)

The sampling flow rate of the LAS 3340 is relatively low, which makes it difficult to achieve low sampling losses. Therefore, we recommend the use of a simple adapter, which serves two purposes: It allows upstream sample dilution with a TSI diluter Model 3302A and, at the same time, increases the flow through the sampling tube to 3 L/min driven by an external sampling pump. The following pictures illustrate the sampling adapter and its use for filter testing.

Schematic of the Sampling Adapter



Photos of the sampling adapter: Parts (upper and lower left) and installation between the LAS 3340 and a Diluter 3302A (upper right)



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