THIN-FILM MILLIMETER WAVE SUBASSEMBLIES

Christopher Bueb and Daniel Murrow

Avantek Incorporated
Folsom, California

ABSTRACT

Thin film millimeter subassemblies, a 35 GHz low noise downconverter and an 18 to 40 GHz dual channel downconverter are described.

The hermetic portion of the 35 GHz downconverter subassembly performs four different circuit functions in a package 1.90" by 0.75" by 0.32". The 18 to 40 GHz dual-channel downconverter subassembly employs three hermetic packages interfaced with small rigid coaxial interconnections. Collectively, these three hermetic packages perform five different circuit functions in a total volume of 1.08 cubic inches.

These downconverter subassemblies are built out of thin-film circuits which offer reduced system size and low interconnection losses.

INTRODUCTION

Traditionally, thin-film millimeter amplifier modules are cascaded and sealed in a hermetic package to perform a single circuit function (amplification). The modular form of an amplifier, however, makes it possible to incorporate many additional circuit functions such as multipliers, mixers, and couplers in a single hermetic package.

These thin-film millimeter subassemblies take advantage of advanced circuit technologies and incorporate rigid coaxial interconnects to mount the hermetically-sealed components in an extremely compact volume. At millimeter frequencies where interconnection and cabling losses can be excessive, the use of subassemblies is advantageous.

A 35-GHz single-sideband low noise downconverter and a dual-channel 18 to 40 GHz downconverter are described in detail as examples of thin-film subassemblies. Block diagrams and module data are given for each subassembly.

CIRCUIT PERFORMANCE

In order to achieve optimum narrowband noise figure in a cascaded amplifier, both single-ended and balanced circuit modules are necessary. Low circuit losses mean that single-ended circuits are lower in noise figure than equivalent balanced circuits. Single-ended circuit noise figures as low as 2.3 dB have been achieved at 35 GHz (see table 1). Unfortunately, single-ended circuits are not usually unconditionally stable. Balanced low-noise gain modules ensure unconditional stability, but their coupler losses make the circuit noise figure too high for input stages. Table 2 shows data for typical balanced 35 GHz gain modules. These circuits have high gain despite their circuit losses because they are optimized for gain rather than noise figure. Narrowband Lange Couplers on the balanced circuits provide the high-end rolloff necessary for image rejection.

#	CURRENT	GAIN	NF	RETURN LOSS IN	RETURN LOSS OUT
	mA	dB	dB	dB	dB
1	11	6.5	2.6	-4.8	-4.9
2	11	5.2	3.1	-4.7	-5.5
3	10	7.2	2.5	-5.9	-6.6
4	11	5.7	2.8	-4.9	-4.6
5	10	6.2	3.0	-5.4	-8.1
6	13	6.8	2.9	-4.6	-18.1
7	13	7.4	2.6	-5.9	-11.6
8	13	6.3	2.3	-7.4	-12.8
9	14	7.1	3.0	-5.5	-26.5

35 GHz SINGLE-ENDED GAIN MODULE DATA
Table 1

#	CURRENT	GAIN	NF	RETURN LOSS IN	RETURN LOSS OUT
	mA	dB	dB	dB	dB
1	32	6.5	3.8	-11.0	-13.0
2	32	6.4	3.5	-11.5	-12.5
3	27	6.3	4.2	-11.3	-11.8
4	26	5.2	6.1	-12.5	-15.1
5	30	6.9	4.1	-13.1	-19.8
6	34	7.2	4.7	-12.4	-28.0
7	35	7.1	4.6	-13.9	-10.9
8	31	7.8	4.4	-12.0	-12.0
9	33	7.0	5.2	-11.0	-12.0
10	31	7.0	5.2	-10.5	-7.8

35 GHz BALANCED GAIN MODULE DATA
Table 2

The 18 to 40 GHz low-noise gain modules are schematically similar to the 35 GHz balanced modules. Broad-bandwidth performance was achieved by reducing the spacing of the Lange Coupler fingers. Typical performance data are shown in table 3.

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#	GAIN 18 GHz dB	29 GHz dB	40 GHz dB	NOISE FIGURE 18 GHz dB	40 GHz dB
1	5.4	5.4	5.0	8.1	7.9
2	5.8	4.8	4.5	8.3	8.0
3	4.5	6.4	4.5	8.9	8.7
4	5.4	4.5	4.5	8.4	8.7
5	4.3	5.1	4.1	8.1	7.3
6	5.3	5.6	5.0	7.1	6.8
7	5.6	4.8	4.1	6.7	8.4
8	4.2	3.7	3.9	8.7	8.9

18 TO 40 GHz BALANCED GAIN MODULE DATA
Table 3

Both subassemblies use the same single-balanced mixer. Thin-film and lumped tuning elements optimize the match to a beam-lead Schottky diode pair. A lowpass filter on the mixer substrate insures good IF isolation. Wideband performance data are shown in table 4.

RF GHz	LO GHz	CONVERSION LOSS #1 dB	#2 dB	#3 dB	#4 dB
18.0	21.3	10.5	11.1	9.0	8.5
20.0	23.3	10.9	11.0	8.9	9.5
23.0	26.3	9.2	10.0	6.6	7.0
26.5	29.8	8.4	11.0	8.5	9.0
30.0	26.7	8.7	10.8	8.8	8.4
33.0	29.7	6.1	7.1	7.5	7.4
35.0	31.7	10.4	8.2	8.6	9.1
36.0	32.7	8.3	10.2	8.1	9.0
40.0	36.7	10.5	10.2	9.2	8.6

18 TO 40 GHz SINGLE BALANCED THIN-FILM MIXER DATA (3.3 GHz IF)
Table 4

All of these circuits use hybrid matching technologies on 10-mil-thickness alumina substrates. Proprietary FETs were used to achieve the low noise figures. The circuit modules are all the same size and have the same center-launch configuration. Fitting these modules into the amplifier cases required very few case modifications.

35 GHz LOW NOISE DOWNCONVERTER

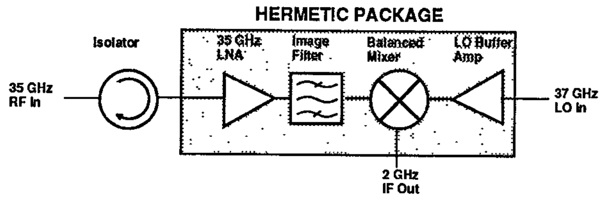
A high-side LO signal downconverts a 35 GHz RF input signal to a 2 GHz IF output. A minimum conversion gain of 16 dB was achieved

FREQUENCY RF GHz	LO GHz	CONVERSION GAIN dB	SINGLE SIDEBAND NOISE FIGURE dB	ISOLATION LO-RF dBc	LO-IF dBc
34.9	36.9	17.2	4.2	>65.1	33.6
35.0	37.0	16.7	4.3	>65.1	33.7
35.1	37.1	16.0	4.4	>65.1	33.8

35 GHz DOWNCONVERTER FINAL DATA
12 Volts @ 153 mA, IF = 2 GHz
Table 5

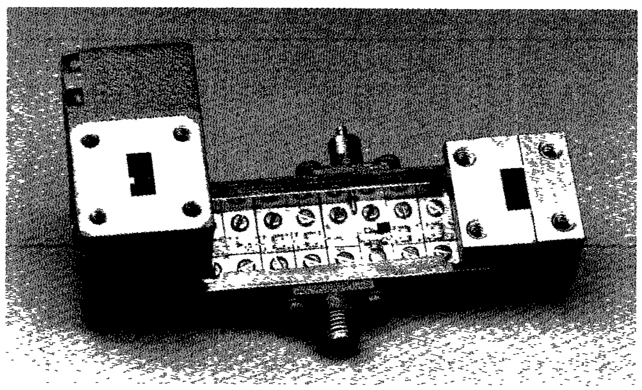
with better than 17 dB image rejection. A maximum noise figure of 4.4 dB was achieved over the downconverter's 200 MHz bandwidth. Final data for the finished unit is given in table 5.

Figure 1 shows the block diagram of the 35 GHz low-noise downconverter. The LNA/image-reject-filter portion of the subassembly has two single-ended low-noise gain stages followed by two balanced image-rejecting gain stages. The output of this cascade feeds into the RF port of a thin-film mixer. Two additional balanced gain stages optimized at 37 GHz provide LO amplification and buffering. An in-line voltage regulator completes the hermetic cascade. This sealed package is quite compact with a total size of 1.90" long by 0.75" wide by 0.41" high.



35 GHz Downconverter Functional Block Diagram
Figure 1

The complete downconverter subassembly model is shown in figure 2. The unit uses WR-28 waveguide for both the RF and LO port connectors with SMA for the IF port. An external isolator at the RF port improves return loss and insures unconditional stability. The housing is machined aluminum, and uses glass feedthroughs for the hermetic seals at the various RF and DC ports. An aluminum cover welded to the main housing completes the hermetic seal.



The Complete Downconverter Subassembly Model
Figure 2

Table 6 shows the computer simulation for the LNA/mixer cascade. Typical circuit modules were used in this cascade. The insertion loss of the isolator, waveguide adapter, and glass feedthrough add directly to the overall noise figure. The noise contribution of the four gain stages and the mixer brought the noise figure to 4.3 dB.

	GAIN dB	NOISE FIGURE dB	NOISE FIGURE DEGRADE dB
Isolator	-0.25	0.25	0.25
Adaptor	-0.10	0.10	0.10
Feedthru	-0.20	0.20	0.20
Gain Stage	5.30	2.60	2.60
Gain Stage	5.90	3.30	0.74
Gain Stage	7.10	4.40	0.26
Gain Stage	6.80	6.60	0.08
Mixer	-8.00	8.50	0.03
Total	16.55	4.26	

Computer Simulation of 35 GHz LNA/Mixer Cascade
Table 6

Figure 3 shows a block diagram of the noise figure setup used to measure the downconverter. Double downconversion was necessary to convert the IF to a frequency that the noise figure receiver would accept. The resultant noise figure indicated by the meter is a sum of the upper side band and the lower side band. Since the upper side band is attenuated (>17 dB), its contribution is insignificant.

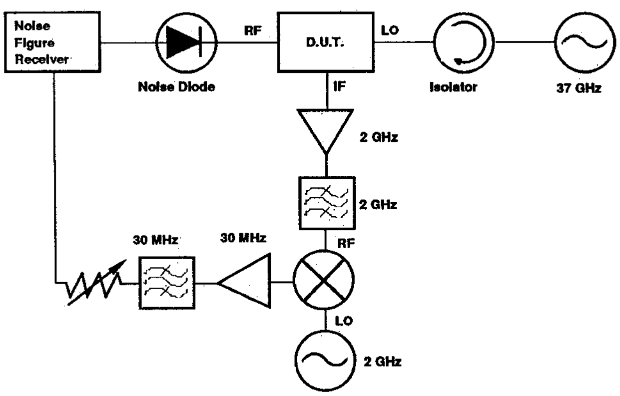
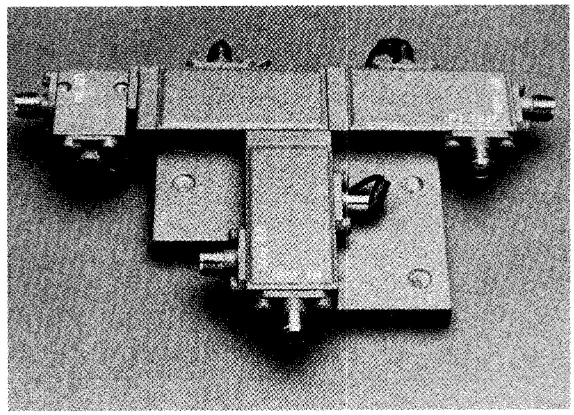


Diagram of Noise Figure Test Set-Up for 35 GHz Downconverter
Figure 3

Conversion gain was measured with a power meter. The input power was measured at each RF test frequency and compared with its IF output power. One dB gain conversion compression was better than -2 dBm IF output power.

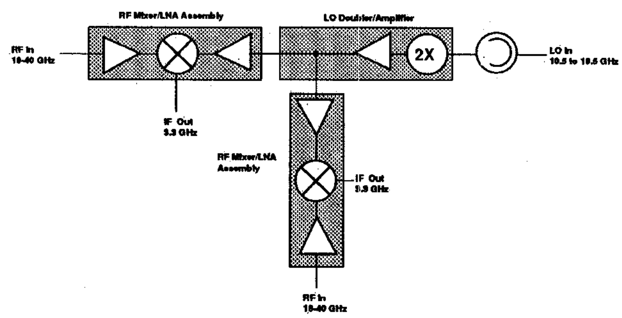
High LO to RF isolation was an inherent part of the downconverter design. The high reverse isolation of the RF amplification modules and input RF isolator made the isolation greater than 65 dB. The low-pass filtering on the thin-film mixer at the IF port resulted in LO to IF isolation of 33 dB.



18-40 GHz Dual-Channel Downconverter
FIGURE 4

18 to 40 GHz DUAL-CHANNEL DOWNCONVERTER

The 18 to 40 GHz dual-channel downconverter consists of three separate hermetic packages, two RF mixer/LNA assemblies and an LO coupler-/amplifier assembly. The model and block diagram are shown in figures 4 and 5.

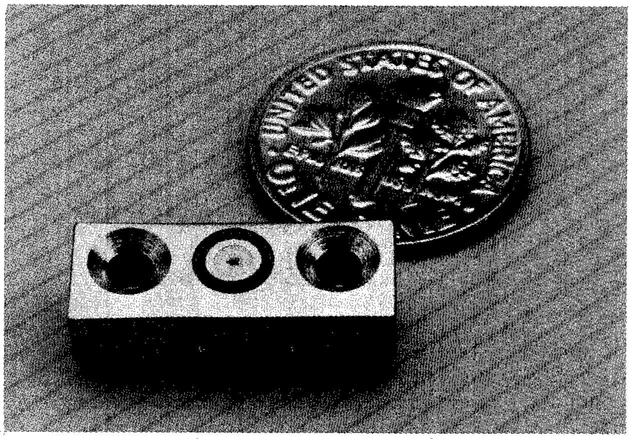


Functional Block Diagram of 18-40 GHz Dual Channel Downconverter
FIGURE 5

The LO doubler-/amplifier consists of a frequency doubler module followed by an in-line voltage regulator, three stages of amplification and a power splitter. A thin-film doubler multiplies the 10.5 to 18.5 GHz signal to produce 21 to 37 GHz. This LO signal passes through the in-line voltage regulator and is amplified by the 21 to 37 GHz gain modules before it is fed into a thin-film Wilkinson power splitter. The Wilkinson power splitter routes the two LO signals out of the hermetic package. An isolator is mounted to the input of this package to improve LO VSWR.

The two hermetic RF mixer/LNA packages are identical. Each package consists of an 18 to 40 GHz LNA gain modules feeding into the RF port of a single-balanced mixer. This RF gain stage lowers the overall conversion loss and noise figure while it improves RF VSWR. Each of these RF mixer/LNA packages houses three LO buffer stages, and an in-line voltage regulator. The total volume of the three hermetic packages is 1.08 cubic inches.

Interconnection between hermetic packages within the subassembly is accomplished with rigid coaxial interconnects. These slip-on transitions mate with the 12-mil feedthrough pins to electrically join the two hermetic packages. The interconnect consists of a beryllium copper sleeve captured by a PTFE insulator in a stainless steel housing (see figure 6).



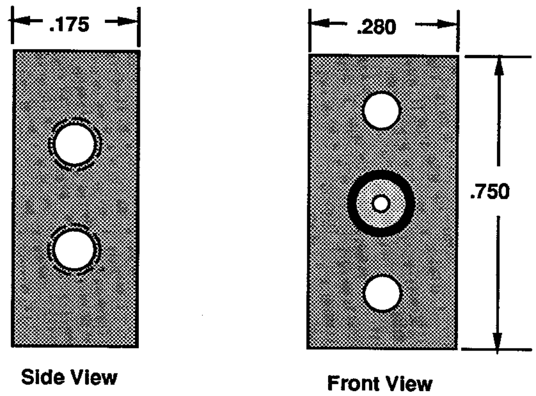
Coaxial Interconnect Photo
FIGURE 6

The housing has three in-line through holes (shown on the front view of figure 7). The two outside holes accommodate K-connector mounting so that the interconnect can be tested before it is put into the subassembly. The inside hole houses the center pin and the PTFE dielectric. EMI gaskets are concentrically placed on both sides of the interconnect housing to reduce RF leakage. A set of threaded holes (shown side view figure 7) was provided for bolting the interconnect down to the baseplate. With a length of 0.175", these interconnects offer a maximum insertion loss of 0.2 dB at 40 GHz.

This subassembly uses a high-side LO to downconvert an 18 to 26.5 GHz RF input to an IF of 3.3 GHz, and a low-side LO to downconvert 26.5 to 40 GHz to the same IF. A typical maximum conversion loss of 9.5 dB and a noise figure of 10.5 dB was obtained. LO to RF and LO to IF isolation were 40 dB. RF to IF isolation was 30 dB. Performance data is listed in table 7 and shown in figure 8.

FREQUENCY GHz		CONVERSION LOSS dB		NOISE FIGURE dB		ISOLATION dBc		
LO	RF	CH 1	CH 2	CH 1	CH 2	LO-RF	LO-IF	RF-IF
10.7	18	9.1	9.1	7.9	9.0	>50	43	20
13.7	24	4.5	5.3	9.1	9.3	>50	>50	29
12.8	29	5.4	5.1	5.6	8.3	>50	>50	41
15.8	35	5.5	5.4	8.7	8.5	>50	>50	37
18.3	40	8.9	8.9	8.9	8.5	>50	46	30

18-40 GHz Dual-Channel Downconverter
+15 Volts @ 403 mA, IF = 3.3 GHz
Table 7



Coaxial Interconnect Drawing
FIGURE 7

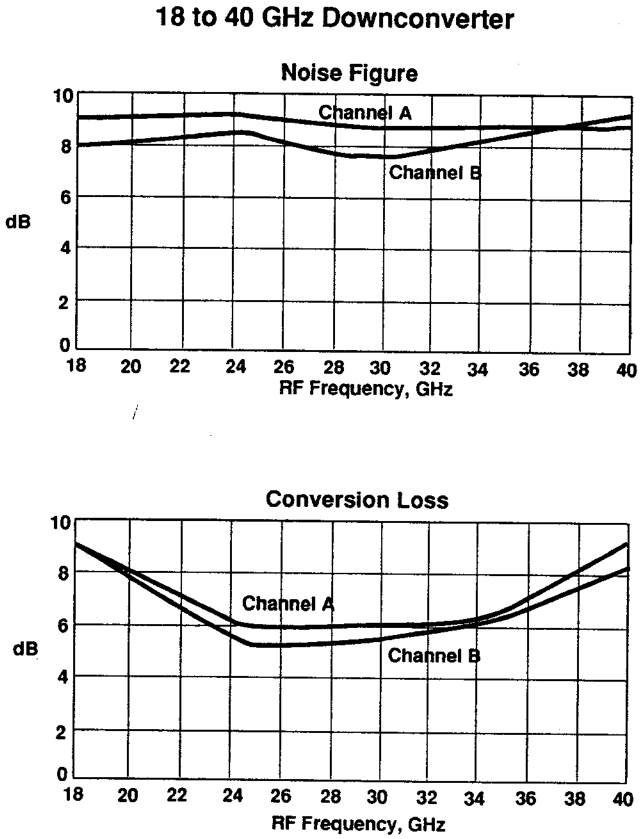


FIGURE 8

CONCLUSION

Reliability and physical size are enhanced with the use of subassemblies. System reliability is improved when subjected to harsh environments by reduced RF connection failure rates. Overall system size is reduced by the elimination of cabling and package connections that would typically be used in assembling single function component architecture. System designs where space constraints and optimum performance are critical can take advantage of thin-film subassemblies.