Low Cost Microwave Receiver Protectors/AGC's Using Surface Mount Components

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Abstract

As the frequency of commercial systems continues to increase, cost solutions to various microwave functions are needed. A low cost solution to receiver protection and receiver AGC functions is presented. This low cost approach is based on use of surface mount techniques for all components in the assembly.

Introduction

The challenge of this effort was to design, develop, test and bring into production a receiver protector(RP)/AGC that would simultaneously meet a number of parameters including, low cost, ease of production in 'moderate' production rates, and modest electrical performance. The design was aimed at insertion in a low cost receiver integrated microwave assembly (IMA), show in Figure 1, for use in the Northrop Grumman family of Modar commercial airborne weather radars. Figure 2 shows the block diagram of the assembly. This approach would also be applicable to any military or commercial system needing a low cost receiver protector or AGC.

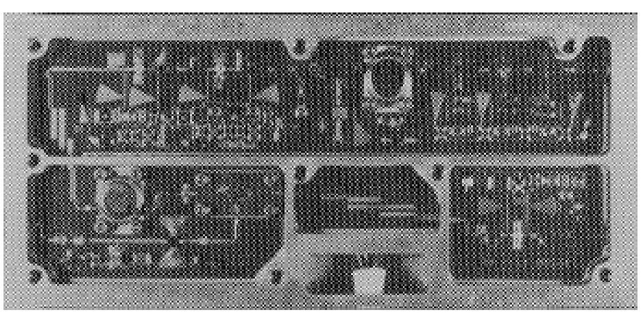

Figure 1. Receiver IMA for Modar Radar.

While the use of bare chip PIN diodes provided the best performance [1,2] in terms of low insertion loss, broad bandwidth and high power limiting, the need for low cost and ease of production were the primary objectives and precluded the use of 'chip and wire' technology for two reasons. First, the cost of assembly is higher than use of packaged parts due to the hand bonding required of the bare chip PIN diodes. Second, a hermetic package would be required, driving up the cost of the package. Use of surface mount packaged components with automated solder reflow would address both these problems. One possible approach using surface mount components is to use a series capacitor [3] to tune (series resonate) out the series inductance of the package. While this approach might provide the best performance (isolation bandwidth), this approach was problematic as any variation in package inductance would require changing the series tuning capacitor.

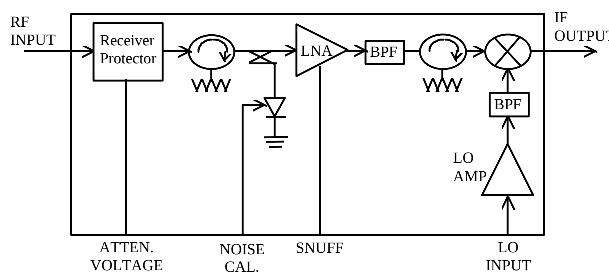

Figure 2. Block Diagram for Receiver IMA for Modar Commercial Weather Radar.

While the performance requirements of the RP could not be considered state of the art, the electrical requirements taken in conjunction with the need for low cost, and ease of assembly did require a novel approach to the design. Table 1 shows the performance requirements for the RP/AGC. The use of surface mount components at X band presents a number of challenges. First, finding a packaged PIN diode that is compatible with surface mounting and solder reflow at a low cost with relatively low values

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of parasitic package capacitance and inductance was required. Second, the need for a circuit topology that could tune out the parasitic package capacitance and inductance to allow for a low loss high isolation circuit.

Table 1. Performance Requirements for the RP/AGC.

Parameter	**Requirement**	**Units**
Frequency	9.3 - 9.5	GHz
Insertion Loss	1.4 max.	dB
Return Loss	20 min.	dB
Attenuation Range	50 min.	dB
Power Handling		
Synchronous Leakage 20 Watts @ 260 usec PW, 10 % Duty	15 max.	dBm
Asynchronous Leakage 20 Watts @ 8 usec PW, 0.4 % Duty	15 max.	dBm

Design Approach

The RP/AGC developed at Northrop Grumman, demonstrated that a low cost easily produced X band RP/AGC could be built in production quantities while still meeting the required performance. The RP/AGC was built as part of a receiver IMA (Figures 1 & 2) for the Modar radar. Included in the IMA are the RP/AGC, LNA, image rejection filters, LO buffer amplifier, and first down conversion mixer and an IF gain stage.

The most difficult component in the design of the RP/AGC was the selection of the PIN diode, as previously mentioned. Requirements for the PIN diode included finding a package that was low cost, compatible with surface mounting, had low parasitic admittance which would allow for low insertion loss over a reasonable bandwidth, and was capable of providing adequate protection for the LNA. Frequency Sources had just developed a low cost surface mountable PIN diode package with low parasitic admittance (package No. 150-1). Table 2 shows the diode parameters used in the design. The package consisted of an end metalized alumina substrate with the PIN diode chip bonded across the top and then epoxy encapsulated. The high power stage consisted of two parallel GC4722's, and the two low power stages consisted of single GC4731's.

Table 2. Diode Parameters for RP/AGC Design.

Parameter	**High Pwr Stage**	**Low Pwr Stages**	**Units**
Junction Capacitance	0.3	0.1	pF
Series Resistance	1.0	2.0	Ω‘s
Parallel Resistance	2000	2000	Ω‘s
Package Inductance	0.4	0.4	nH
Package Capacitance	0.15	0.15	pF

Figure 3 shows the schematic of a the RP/AGC. All components are surface mounted using solder reflow techniques to ease assembly. One of the goals in the design of the circuit, was to have the ability to both tune out the package admittance and diode capacitance, while still providing the flexibility for tuning out any variations that may occur in the package or diode without replacing components. To perform this task requires the tuning elements be open circuit stubs which can be accurately controlled, but easily varied if required (versus shorted stub tuning which is not easily varied).

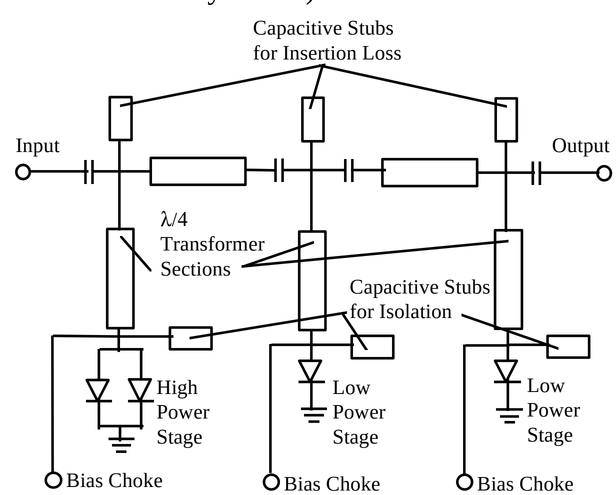

Figure 3. Schematic for RP/AGC.

To determine the amount of shunt capacitive tuning, in the limiting mode of operation, the series package inductor/diode resistor must be transformed into an equivalent shunt circuit. The shunt inductance can now be resonated by a shunt capacitance i.e. a distributed open circuit stub. The shunt resistance in the equivalent circuit is now too large to provide and useful limiting. To present a low resistance to the 50 Ω transmission line, a quarter wavelength transmission line is required between the packaged diode and the main 50 Ω transmission line. The exact length of the quarter wavelength transformer can be

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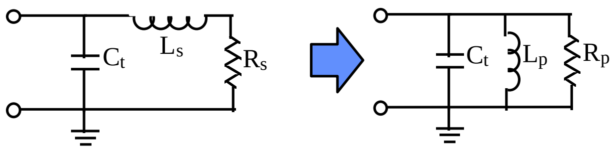
varied to optimize the attenuation of the structure. Figure 4 represents the equivalent shunt circuit for the diode derived from the physical series configuration. Included are the values of the equivalent shunt inductance and resistance derived for the isolation state, from the diode parameters, and the capacitance required to resonate out the shunt inductor.



$$R_p = \frac{X_s^2}{R_s} \qquad X_s = \omega^* L_s$$

$$L_p = L_s$$

Parameter	High Pwr Stage	Low Pwr Stages	Units
L_s	0.4	0.4	nH
R_s	1.0	2.0	Ω‘s
L_p	0.3	0.1	nH
R_p	558	279	Ω‘s
C_t	0.27	0.47	pF

Figure 4. Equivalent Shunt Circuit for the Diode.

When the circuit is in the low insertion loss mode the package and PIN diode isolation tuning described above, presents a shunt capacitive affect at the diode. At the end of the quarter wavelength transformer, this capacitance will appear as a shunt inductor to the main 50 Ω transmission line. This shunt inductance can be resonated out by some shunt capacitance, minimizing the affect on insertion loss. One additional advantage of this structure is that the tuning for maximum isolation is decoupled for the tuning for insertion loss. Tuning can be performed by first modifying the open stub next to the PIN diode used for isolation, next, the stub at the main 50 Ω transmission line can be modified to minimize insertion loss.

Figure 5 shows a photograph of the circuit, the center frequency of which is 9.4 GHz. As can be seen, all components are surface mounted with grounding provided by filled via holes. Shunt capacitance is provided by open circuit stubs, as see in the figure. The stubs were designed with a finite length with additional pads beyond the ends to provide for flexibility in tuning (i.e. to shorten or lengthen) during prototype builds.

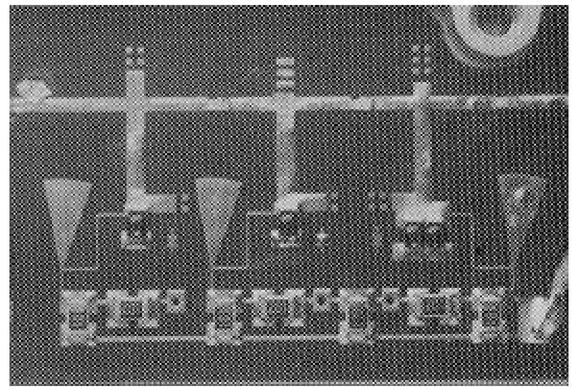


Figure 5. Photograph of RP/AGC Circuit.

Power handling and thermal management of the circuit was accomplished by two means. First, the PIN diodes were placed over the filled vias using solder, providing a direct thermal path to the base plate. Secondly, two high power PIN diodes were used as the first stage providing a factor of four improvement in power handling over the use of a similar single diode. This is due to the fact that each diode now only handles half the power so the current is reduced by a factor of four (as the I*V dissipation in the diode is reduced by a factor of four).

Using a microwave CAD program, the circuit was designed using values provided by the vendor’s PIN diode catalogue. The required tuning proved to be easily realized, and as stated above, the tuning for insertion loss had little effect on the isolation which had previously been tuned. Figures 6 and 7 shows the modeled results of the circuit for insertion loss/return loss and isolation respectively.

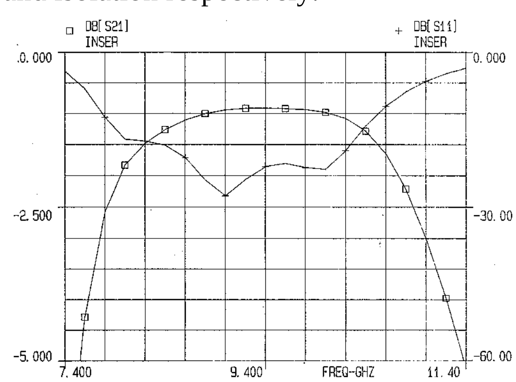


Figure 6. Modeled Results for Insertion Loss and Return Loss.

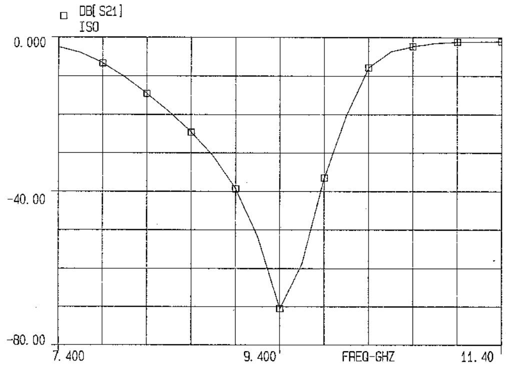


Figure 7. Modeled Results for Isolation.

A breadboard of the circuit was fabricated and measured, the results are shown in Figures 8 and 9. Measured low level results agreed very well with the modeled results. High power results for asynchronous power handling are shown in Figure 10. Synchronous power handling provided the 50 dB of attenuation as expected.

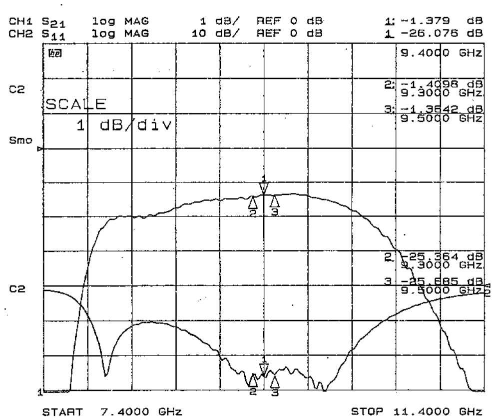


Figure 8. Measured Results for Insertion Loss and Return Loss.

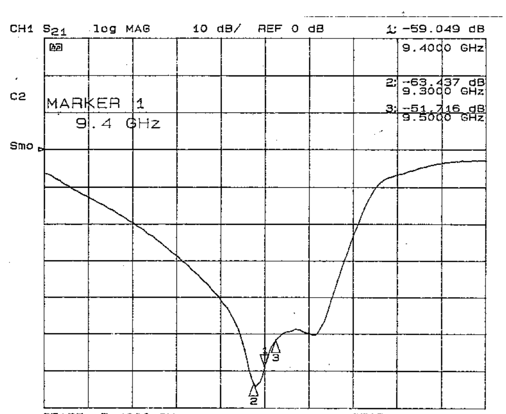


Figure 9. Measured Results for Isolation.

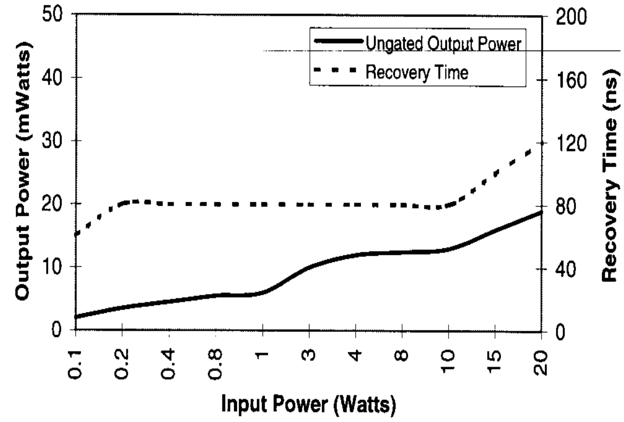


Figure 10. Measured Results for Ungated High Power Attenuation and Recovery Time.

Conclusion

The ability to design and produce a low cost X band receiver protector/AGC using commercial components in a surface mount configuration has been demonstrated with over 300 units having been built. While optimized for X band operation, the approach presented in this paper could be scaled both up and down in frequency for different applications. While commercial systems typically do not require the RP function, AGC and front end (high power) switch are functions needed in commercial communication systems.

References

[1] P. Sahjani,"PIN Diode Limiters Handle High-Power Input Signals", Microwaves and RF,pp. 195-199, April 1990.

[2] M. Gawronski and H. Goldie,"200W MIC L-Band Receiver Protector", Microwave Journal, pp. 43-46, April 1977.

[3] E. Niehenke, T. Steigerwald and A.Lisenbardt, "New Limiters Protect Low-Noise Amps", Microwaves and RF, pp. 89-96, February 1984.