using Boulder Microwave Technologies’s Ensemble 5.1. The simulated bandwidth for VSWR = 2.0 is 52 MHz (2.3%), and the bandwidth for an axial ratio less than 3 dB is 13 MHz (0.51%). The return loss at the resonance frequency is 27.6 dB, and the axial ratio is 0.63 dB.

The measured center frequency is 2.212 GHz, which shows a 1.7% error for the 2.25 GHz design frequency. The measured bandwidth is 60 MHz, and the return loss is –28.8 dB at the 2.212 GHz center frequency. Figure 3 compares the designed axial ratio with the simulated one using Ensemble. The axial ratio simulated by Ensemble is 1.25 dB at 2.241 GHz, which shows a 0.04% difference for the simulated data. The bandwidth for an axial ratio less than 3 dB is 14 MHz.

V. CONCLUSION

In this paper, we have presented a new design method for a coaxially fed circularly polarized rectangular microstrip antenna using a GA. The usefulness of a GA for the complicated object function was illustrated by designing the circularly polarized microstrip antenna. The size and the feeding point were optimized for the given substrate properties and the operating frequency. The computed return loss was 27.6 dB, the bandwidth was 52 MHz (2.3%), and the operating frequency showed a 1.7% error for the measured data. The axial ratio bandwidth was 13 MHz (0.51%), and showed a 0.04% difference for the simulated data using Ensemble.

REFERENCES

In order to implement effective protection against ESD events, the behavior of the device in question under ESD conditions must be known. The most accurate way of predicting the effects of an ESD event in any device is to analyze the heat dissipated in the device during a high-current stress event [4]. An analytical approach to this is to solve the heat conduction equation for the particular device geometry under consideration:

\[
\frac{\partial T}{\partial t} - D \cdot \nabla^2(T) = \frac{q(t)}{\rho \cdot C_p} \tag{1}
\]

where \( \rho \) is the density of the material, \( C_p \) is the specific heat, \( D \) is the thermal diffusivity, and \( q(t) \) is the rate of heating per unit volume of the heat source. This procedure requires the solution of a partial differential equation subject to boundary conditions from the geometry of the device under consideration. In the general case, the solution of Eq. (1) can be quite involved.

II. METHOD

Here, we present a simpler approach that is independent of the microbolometer’s geometry. This approach uses an equivalent thermal circuit consisting of a parallel combination of a thermal resistance and a thermal capacitance [5]. The thermal impedance \( Z_{th} \) for our model is given by

\[
Z_{th}(s) = \frac{R_{th}}{1 + s \cdot R_{th} \cdot C_{th}} \tag{2}
\]

where \( R_{th} \) and \( C_{th} \) are the thermal resistance and capacitance of the bolometer, and \( s \) is the Laplace complex-frequency variable. The rise in temperature \( \Delta T \) in the device under ESD stress is given by

\[
\Delta T = T - T_0 = P \cdot Z_{th} \tag{3}
\]

where \( P \) is the power dissipated, \( T \) is the final temperature, and \( T_0 \) is the initial temperature. We assume, as a worst case scenario, that all power generated by the ESD event is dissipated in the device. The transmission-line pulsing (TLP) method is used to characterize the ESD event [6], modeling it as a square pulse with a width in the 100–200 ns range. The power is given by

\[
P_{\text{ESD}} = \frac{V_{\text{ESD}}^2}{R_b} \tag{4}
\]

where \( V_{\text{ESD}} \) is the electrostatic potential generated and \( R_b \) is the electrical dc resistance of the microbolometer. The Laplace domain expression for the power generated by an ESD event is

\[
P(s) = \frac{V_{\text{ESD}}^2}{R_b} \cdot \left( \frac{1 - e^{-\tau s}}{s} \right) \tag{5}
\]

where \( \tau \) is the duration of the ESD pulse. The temperature of the bolometer as a function of time [Eq. (3)], which results from an ESD event, can be found by the inverse transform of the product of the thermal impedance [Eq. (2)] and the power generated [Eq. (4)]:

\[
T(t) = L^{-1}\{Z_{th}(s)P(s)\} \tag{6}
\]

where \( u(t - \tau) \) is the unit-step function. Equation (7) shows that the temperature is a function of the measured characteristics of the bolometer \( R_{th}, C_{th}, \) and \( R_b, \) and of the characteristics of the ESD event \( V_{\text{ESD}} \) and \( \tau. \) A typical temperature response resulting from an applied voltage can be seen in Figure 1, where the case of a square pulse with \( \tau = 200 \) ns and \( V_{\text{ESD}} = 1 \) V is considered.

The responsivity of the bolometer is the output voltage per unit input power \((V/W)\), and is given by

\[
\eta = \alpha \cdot |Z_{th}| \cdot V_b \tag{8}
\]

where \( \alpha \) is the temperature coefficient of resistance of the sensor material and \( V_b \) is the dc bias voltage across the device [7]. Plotting the bolometer’s response (in volts) per incident power as a function of the modulation frequency yields the responsivity curve. Using Eqs. (2) and (8), values for \( R_{th} \) and \( C_{th} \) can be obtained, noting that \( R_{th} \) determines the dc responsivity, and that the product of \( R_{th} \) and \( C_{th} \) represents the time constant of the device.

III. RESULTS AND DISCUSSION

The proposed thermal model was fitted to measurements made on antenna-coupled niobium microbolometers with a mean dc resistance of \( R_b = 195 \) \( \Omega \). These bolometers are used for the detection of infrared radiation with wavelengths around 10 \( \mu \)m. The sensing element is a niobium patch of dimensions 1.5 \( \mu \)m \( \times \) 350 nm with 50 nm thickness [8]. The responsivity measurements were made using a focused CO2 laser beam with a wavelength of 10.6 \( \mu \)m and an acousto-optic modulator [9]. Figure 2 compares the thermal model and the measured data. In order to obtain the bolometer’s effective responsivity, the conversion ratio of optical to electrical power must be known. This is obtained by normalizing the optical responsivity curves to the power dissipated in the bolometer [7]. Using Eq. (7), a graph of the temperature versus ESD-induced voltage for a step function ESD event can be obtained.
This describes the steady-state thermal behavior of the microbolometer after a voltage is applied. Figure 3 illustrates this behavior for a 197 Ω niobium microbolometer, showing that the microbolometer’s temperature reaches the melting point of niobium at a voltage of 0.68 V. Destructive tests were performed on eight microbolometers with resistances of 195 ± 5 Ω and time constants of 123 ± 6 ns. A failure voltage of 0.65 ± 0.05 V was recorded for these devices. The temperature versus voltage curve shown in Figure 3 is useful in determining the vulnerability of the microbolometer to the biasing voltage. It is also useful for the determination of the initial temperature conditions of the bolometer, that is, the initial temperature caused only by the ambient temperature and the bias voltage. The power-to-failure versus time-to-failure curve [10] is used to explain the relationship of physical failure to a critical temperature (melting temperature). Figure 4 shows a graph of this type for a 197 Ω Nb microbolometer. This graph was obtained using Eq. (7) and plotting power \( P_{ESD} \) versus the time \( t \) when the temperature reaches niobium’s melting point (failure criteria). The parameters \( R_{th} \) and \( C_{th} \) necessary to generate the graph were obtained from data measured on the Nb microbolometer.

The power-to-failure versus time-to-failure graph gives the power rating and the time response the protection circuit needs to have to effectively protect against ESD events.

**IV. CONCLUSION**

An empirical thermal model was used to characterize the response of microbolometers to electrical stress. This thermal model can be used to make a power-to-failure versus time-to-failure analysis, and therefore determine the robustness of the microbolometers and the protection needed to shield them from ESD events. This model can be used with any kind of microbolometer, and is independent of the geometry, fabrication process, and materials used. The unknown parameters \( R_{th} \) and \( C_{th} \) for the thermal model are fitted to data obtained by direct measurement of the temporal responsivity.

**REFERENCES**


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