Allen Telescope Array

A Wilkinson Divider using coplanar waveguide for the PAM upgrade Design Overview

"Draft September 24, 2020"

Jaz Hill-Valler
Alex Pollak

SETI Institute
189 Bernardo Ave, Suite 200
Mountain View, CA 94043
jhillvaller@seti.org

July 9, 2025

1 Introduction

The PAM module requires that the RF signal is split, the signal must continue to the RF OUT, provide the output for the Fibre bias and some signal go into the detector. In the original PAM module the detector diode consists of lumped components off the RF track, which are then linked via microstrip to the OPAMP and DETECTOR OUT. However, this arrangement of the detector diode has proven to be faulty in some PAM modules, the new replacement detector diode is the ADL6010 module which requires an RF input and cannot be placed off the track. Since the detector is sensitive to a low power output (-30 dBm minimum), the original idea was to design a 10 dB coupler which would send -10dB of the signal to the detector diode and allow the through put to the RF OUT and Fibre BIAS.

The design of a 10 dB coupler in microstrip can be taken from basic design principles, however, when converting to coplanar wave guide some issues arose. In particular in order to achieve a 10 dB coupling ratio, the gap width between the two signal strips must become too small to be able to etch with the 35 micron material. Even with more tolerable designs at -15 dB and -20 dB, there were issues with impedance mismatching and poor return loss due to considerable changes in track width. The design was abandoned in favour of the Wilkinson Divider, a style of three port hybrid. The coupler design could be revisited in the future if time can be allowed for impedance matching and optimisation. Information on the design will be written as supplementary to this document.

After revisiting the cascading gain chain, the maximum power entering the detector diode is well below the maximum allowable power and so additional attenuation wont be needed. Therefore a Wilkinson divider operating at -3 dB will suit the design well. The design of a Wilkinson divider can be found by following basic design principles outlined in this paper. Furthermore, unlike the coupler design, the Wilkinson divider can be easily converted into coplanar waveguide as the gap width remains constant and no transforms are needed.

2 Design process

Since the divider needs to be operational from DC to 12+ GHz, a design formula for a 1:10 bandwidth divider has been used ([1]). To achieve a suitable bandwidth, the design requires the use of a N = 7 step Wilkinson divider, using 7 stepped impedance stages. Each of these stages can be found by using a stripline calculator (TXLine) for a grounded coplanar waveguide. The resulting line widths and design impedance's are given in Table 1.

Each segment must be a quarter wavelength long. Taking the centre frequency to be 7.5 GHz and allowing for the correction of wavespeed in a dielectric, $v_P = \frac{1}{\sqrt{\epsilon_R}}$, where ϵ_R is the dielectric constant. For the Rogers 4350 material, $\epsilon_R = 3.66$, so $v_P = 0.523$. Using the design of the 4 - 16 GHz Goonhilly 4-step Wilkinson divider as a guideline ([2]), circular segments have been used to reduce the length of the divider (see Figure 1). The quarter wavelength corresponds to diameter of each segment, this measurement determines the central frequency. Each ring must overlap in a way that the overlapping section is similar in thickness to the next corresponding segment, this means better impedance matching between segments and a lower return loss. For a centre frequency of 7.5 GHz, the wavelength, $\lambda = v_P \lambda_0$ is 20.92 mm. Therefore $\lambda/4 = 5.23$ mm so the radius of the segment is 2.62mm. This length had a

Step	Normalized Z	Z_0Z (Ω)	Track Width (mm)
Z1	1.1274	56.370	1.2503
Z2	1.2051	60.255	1.0705
Z3	1.3017	65.085	0.8859
Z4	1.4142	70.710	0.7102
Z5	1.5364	76.820	0.5623
Z6	1.6597	82.985	0.4448
Z7	1.7740	88.700	0.3594

Table 1: Table detailed design parameters for the Wilkinson divider.

cut off too low in frequency so small adjustments were made to the radius to get the best band cover. The radius which worked best was 2.58mm, corresponding to a centre frequency of 7.602 GHz.

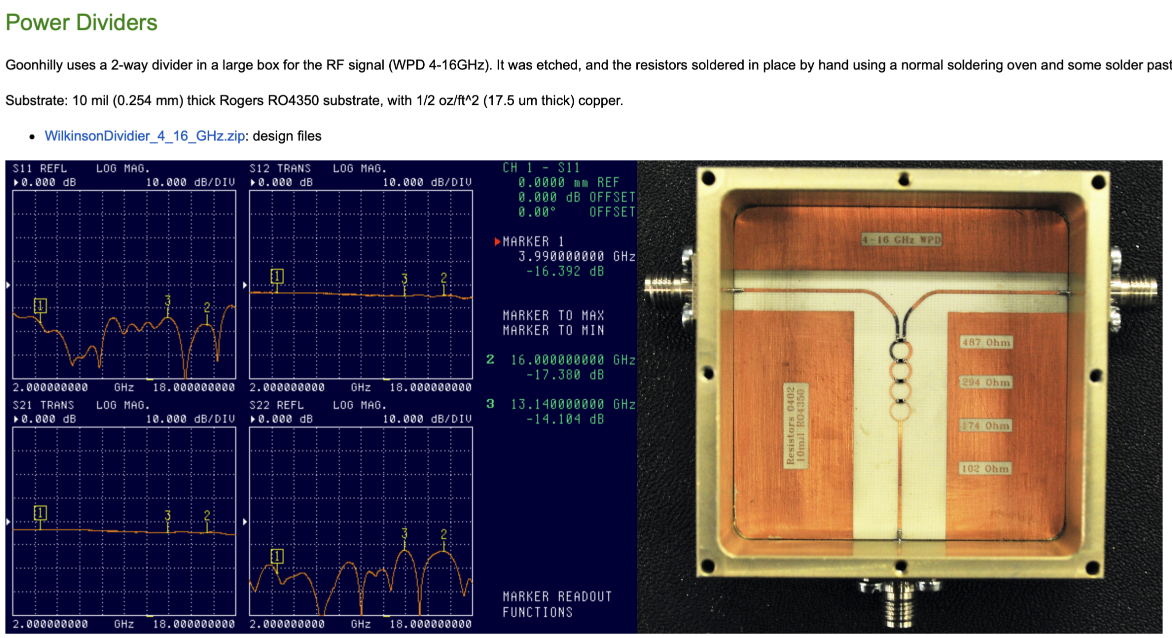

Figure 1: Tested Wilkinson divider used on the Goonhilly optics - showing the use of overlapping rings to get a 2:1 bandwidth response.

3 Simulation

The optimum design is given in Figure 2. There were a few options for the resistors in-between the tracks. A simulation was run without resistors and showed good performance. The resistor values from the design paper gave a worse performance. Typically, for an equal split Wilkinson divider, the resistors are taken to be twice the track width. These resistors gave a comparable performance to the no resistor scenario. The S-parameters of the simulation are given in Figure 3. An optimisation was run for the resistor values however the simulation was unable to converge as performance could not be greatly improved upon by simply changing the resistor values.

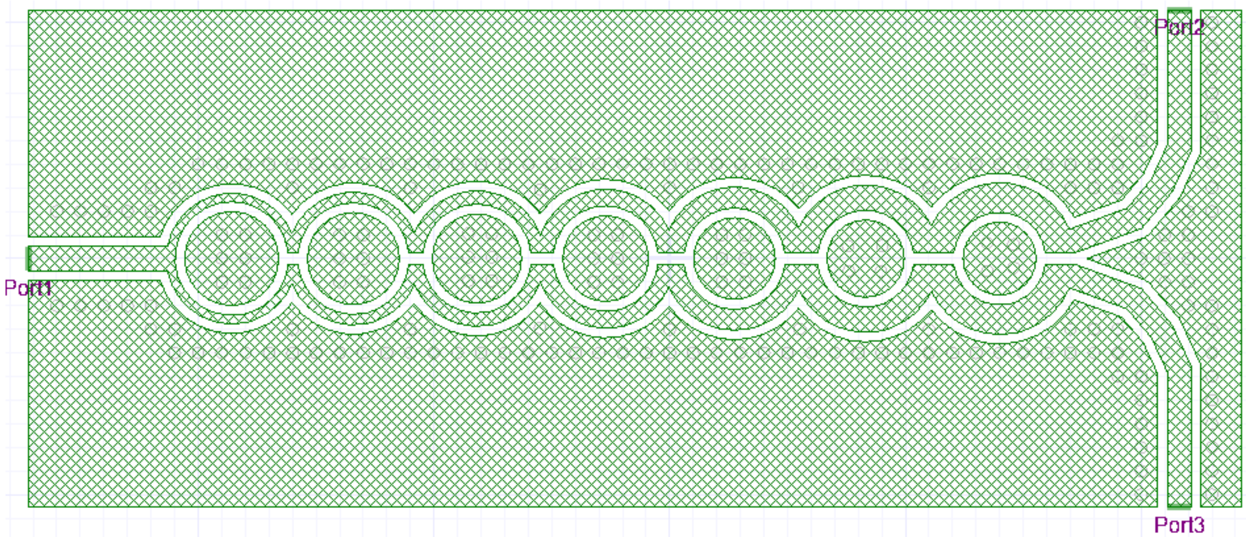

Figure 2: Track layout in HFSS for the 7 step Wilkinson divider.

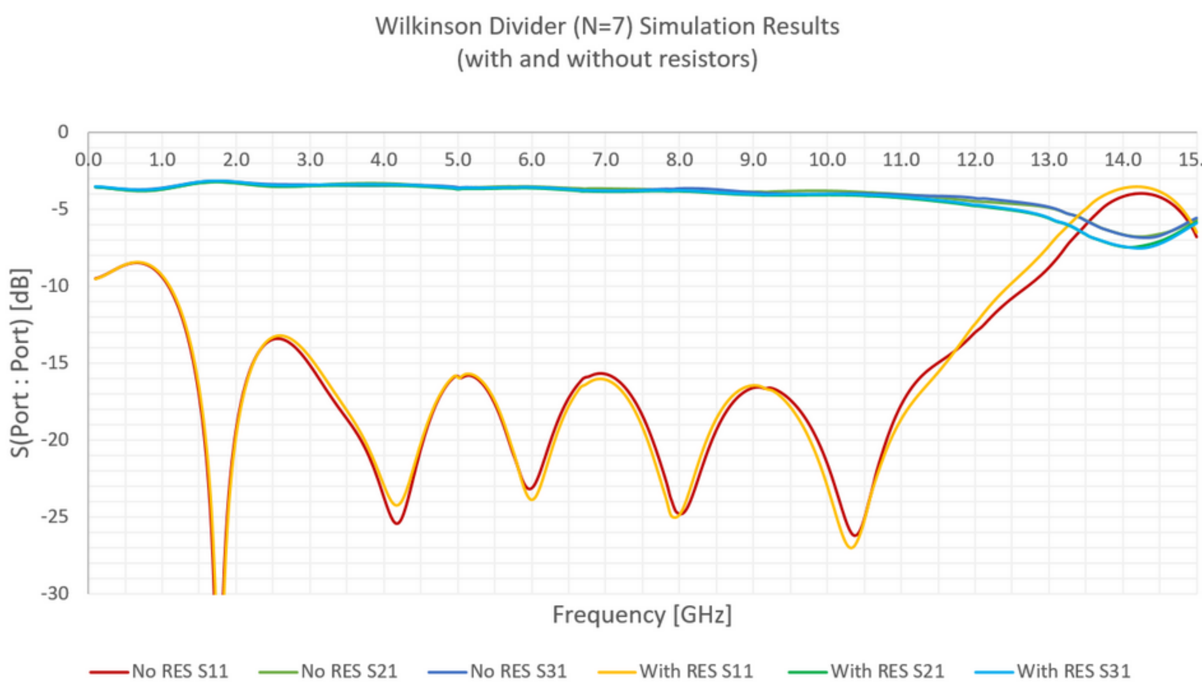

Figure 3: Track layout in HFSS for the 7 step Wilkinson divider.

4 Resistors

The divider will need low tolerance RF resistors to be placed between the tracks. The recommended choice are the Panasonic Thin Film Chip Resistors of the ERA V the series. The specific series number and the resistance of each is given in Table 2.

Resistor	Value (Ohms)	Datasheet
R1	100	ERA-2VEB1000X
R2	120	ERA-2VEB1200X
R3	130	ERA-2AEB131X
R4	143	ERA-2AEB1430X
R5	147	ERA-2AEB1470X
R6	169	ERA-2AEB1690X
R7	178	ERA-2AEB1780X

Table 2: Resistor identifier, value and series name of the Panasonic thin film resistors for the divider part of the PAM RF track.

Bibliography

[1] S. B. Cohn. A class of broadband three-port tem-mode hybrids. *IEEE*, MTT-16, 1968.

[2] A. Pollak. Receiver technology for radio astronomy and deep space communications. *University of Oxford*, pages 151 – 153, 2018.