Mitigation of the ZDR Bias Temperature Dependence

Frank Gekat, Markus Hille, Markus Krings

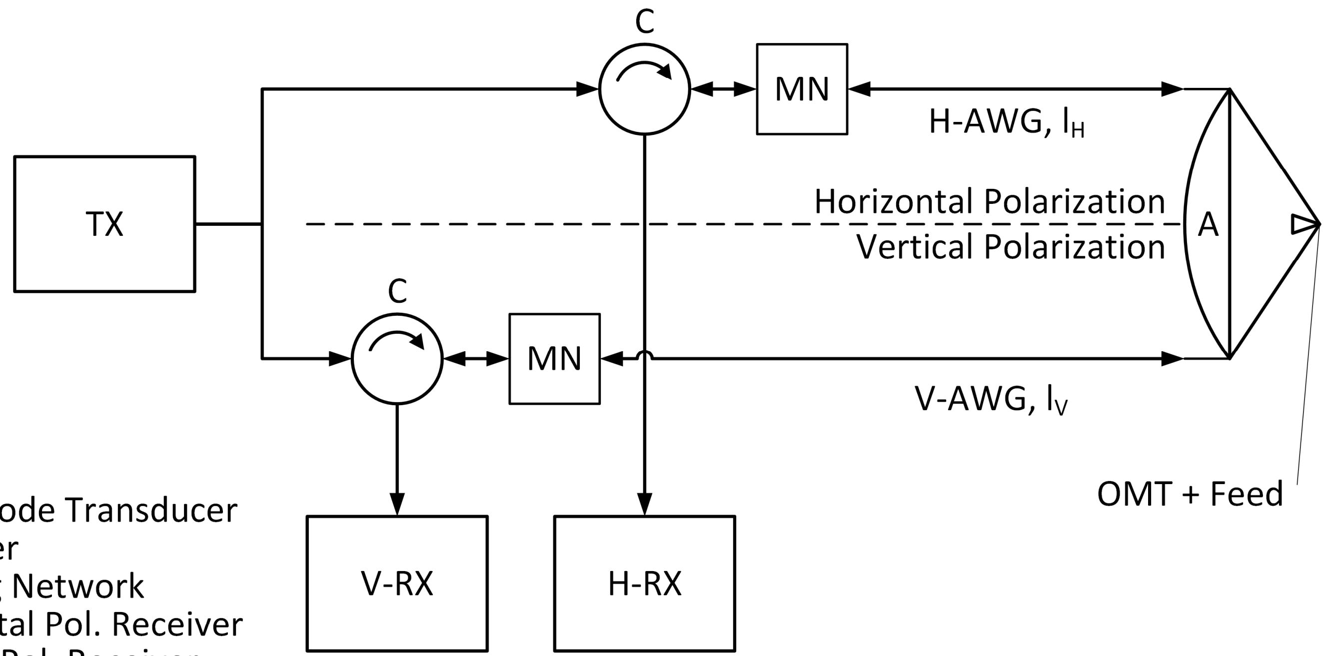
3rd Weather Radar Calibration Workshop, Toulouse, France 2021

17-19 November 2021, Toulouse, France

INTRODUCTION

- It is well known that the ZDR Bias of a polarimetric weather radar shows a dependence on the outdoor temperature see e.g. (1) and (2) (0.2 dB over 12 °C temperature change (1))
- The root cause(s) of this temperature-dependent variance is yet unknown. In most publications it is speculated that it could be the antenna
- In this talk we will show that one possible reason could be the difference in the thermal variations of the horizontal and vertical polarization waveguide circuits between the radar and the antenna
- We will also propose a simple approach to mitigate the effects of these variations
- Furthermore we will indicate some other radar parameters which might have a similar effect

SIMPLIFIED BLOCK DIAGRAM OF A POLARIMETRIC WEATHER RADAR



A: Antenna
C: Circulator
OMT: Orthomode Transducer
TX: Transmitter
MN: Matching Network
H-RX: Horizontal Pol. Receiver
V-RX: Vertical Pol. Receiver

H-AWG: Horizontal Polarization Antenna Waveguide with length l_H
H-AWG: Horizontal Polarization Antenna Waveguide with length l_V

ANTENNA WAVEGUIDE AS A RESONATOR

Resonance frequencies of a TE10n cavity (3)

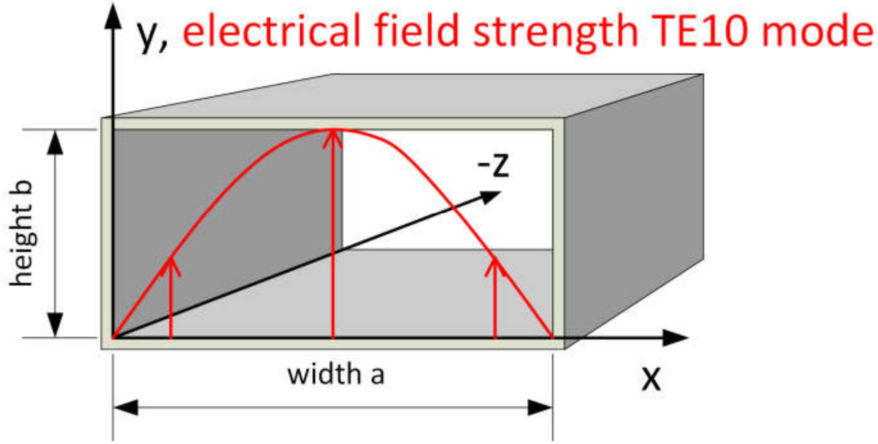
$$f_r = \frac{c}{2\pi}\sqrt{\left(\frac{\pi}{a(T)}\right)^2 + \left(\frac{n\pi}{l(T)}\right)^2}$$

c: speed of light, n: integer, T: temperature

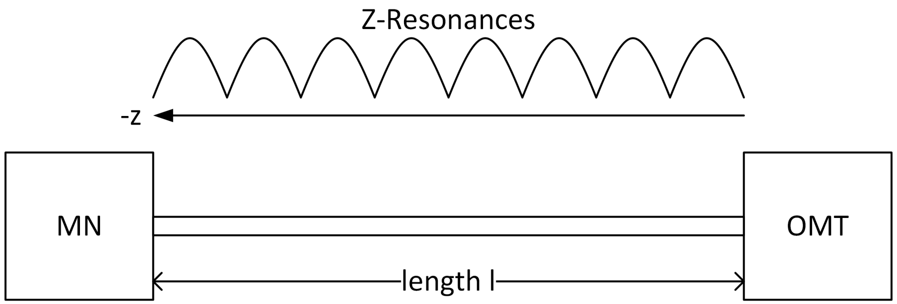
Thermal variations

$$a(T) = a_0(1 + \alpha\Delta T)$$
$$l(T) = l_0(1 + \alpha\Delta T)$$

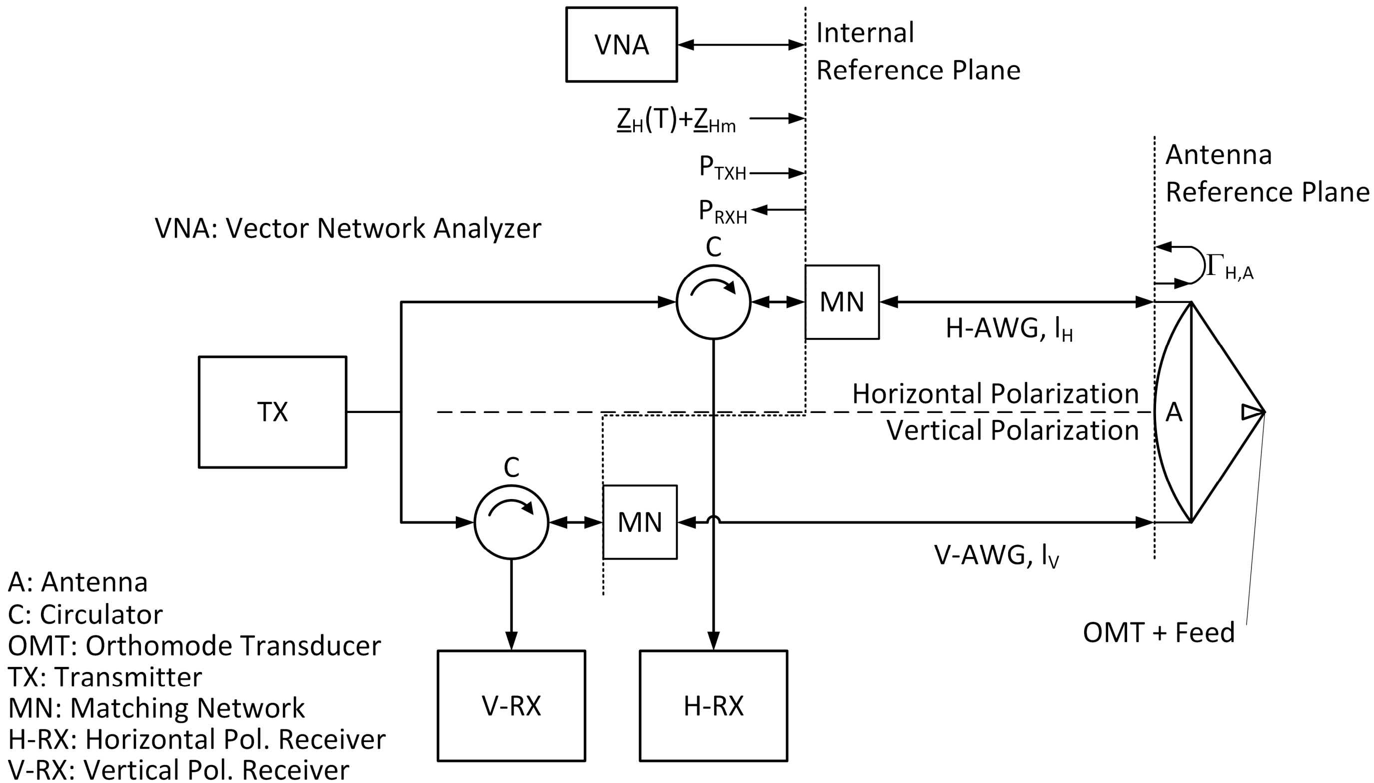
Thermal expansion coefficient of Aluminum: $\alpha_{Al} = 23.1 \cdot 10^{-6}\ K^{-1}$



Wave-guide	**Frequency**	**Width a**	**Thermal Coefficient**	
			Length l, 25 m	**Length l, 5 m**
WR284	2800 MHz	72.14 mm	-64.71 kHz/K	-64.43 kHz/K
WR187	5640 MHz	47.55 mm	-130.23 kHz/K	-129.77 kHz/K



RETURN LOSS AT THE INPUT OF THE MATCHING NETWORK



H-AWG: Horizontal Polarization Antenna Waveguide with length l_H

H-AWG: Horizontal Polarization Antenna Waveguide with length l_V

CALCULATION OF THE RETURN LOSS AT THE INPUT OF THE MATCHING NETWORK

Waveguide wavelength

$$\lambda_g(T) = \lambda / \sqrt{1 - (\lambda / 2a(T))^2}$$

Waveguide phase constant

$$\beta(T) = 2\pi / \lambda_g(T)$$

OMT impedance

$$\underline{Z}_A = (1 + \underline{\Gamma}_A)/(1 - \underline{\Gamma}_A)$$

$\underline{\Gamma}_A$: complex OMT reflection coefficient

All equations from Ref. (4)

Transformed OMT impedance

$$\underline{Z}(T) = Z_0 \frac{\underline{Z}_A + jZ_0 \tan\big(\beta(T) l(T)\big)}{Z_0 + j\underline{Z}_A \tan\big(\beta(T) l(T)\big)}$$

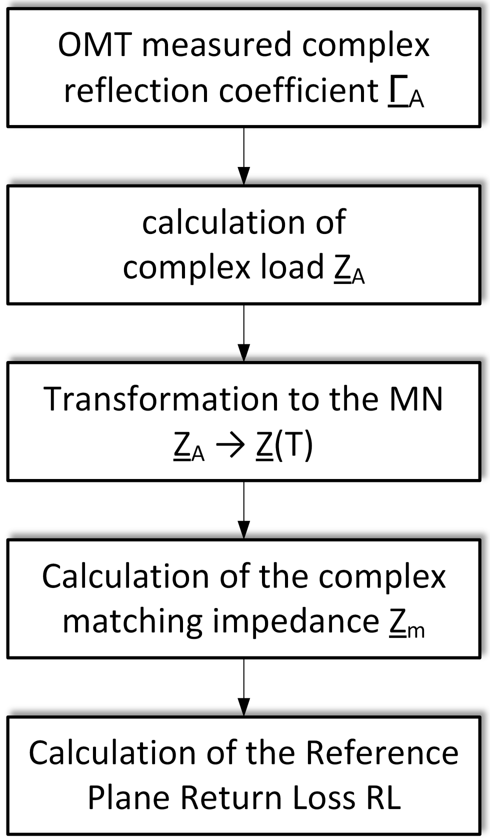
Complex matching impedance

$$\underline{Z}_m = 1 - Re\big(\underline{Z}(T_0)\big) + j(-Im\big(\underline{Z}(T_0)\big)$$

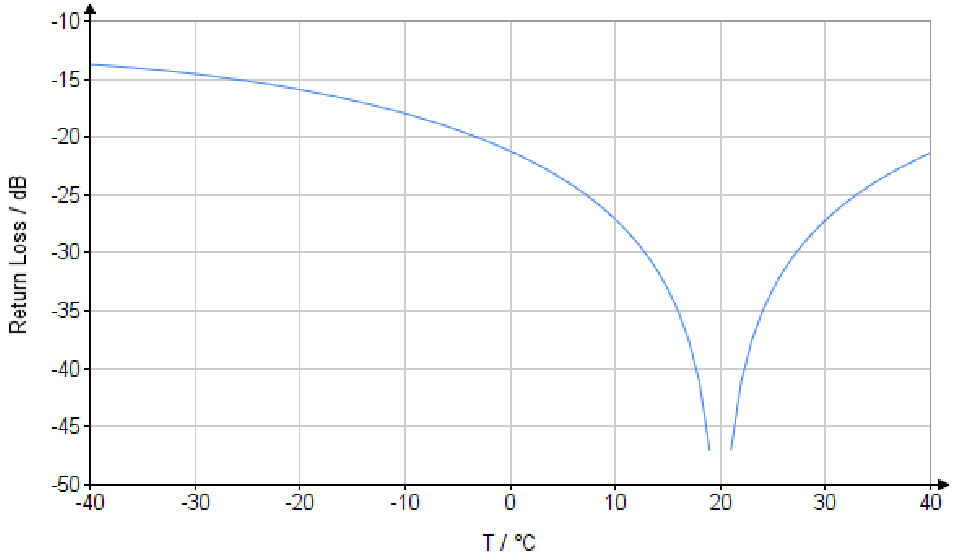
T_0: outdoor temperature during tuning of MN

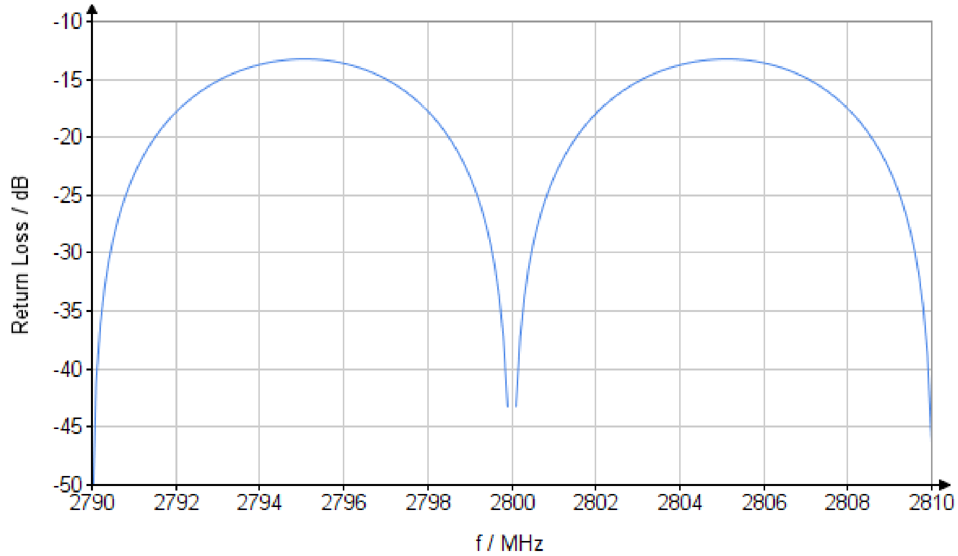
Return Loss in the reference plane

$$RL = \left| \frac{\underline{Z}(T) + \underline{Z}_m - 1}{\underline{Z}(T) + \underline{Z}_m + 1} \right|^2$$



CALCULATION RESULT





Matching Frequency: 2800 MHz

Matching Temperature: 20 °C

Waveguide Length: 10 m

OMT Return Loss: -18 dB

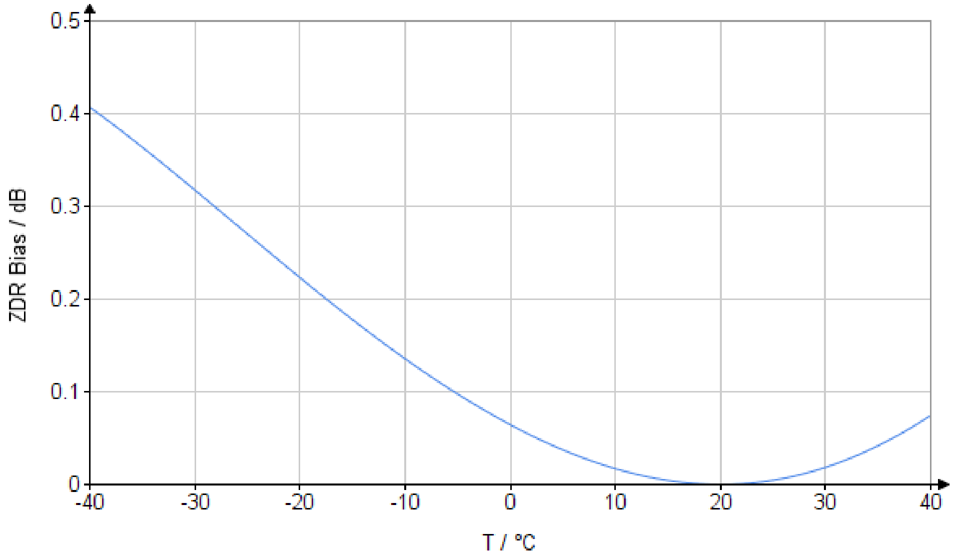
OMT Mismatch Phase: 3π/2

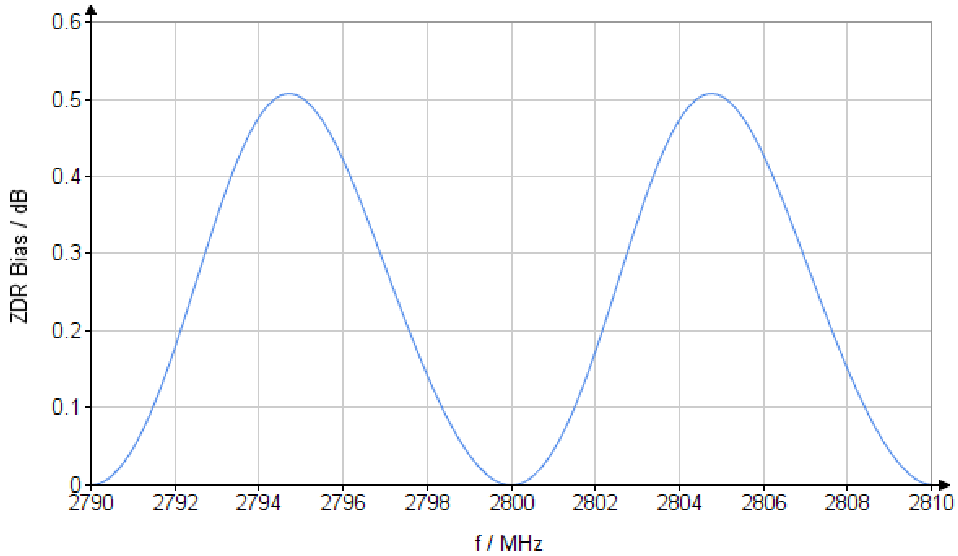
CALCULATION OF THE ZDR BIAS CAUSED BY DIFFERENT RETURN LOSSES

ZDR Bias caused by different return losses of the horizontal and vertical polarization waveguide

$$ZDR_{Bias}(T) = \frac{(1 - RL_H(T))^2}{(1 - RL_V(T))^2}$$

RLmax ≤ -20dB
⟹ max. ZDR Bias ±0.087 dB



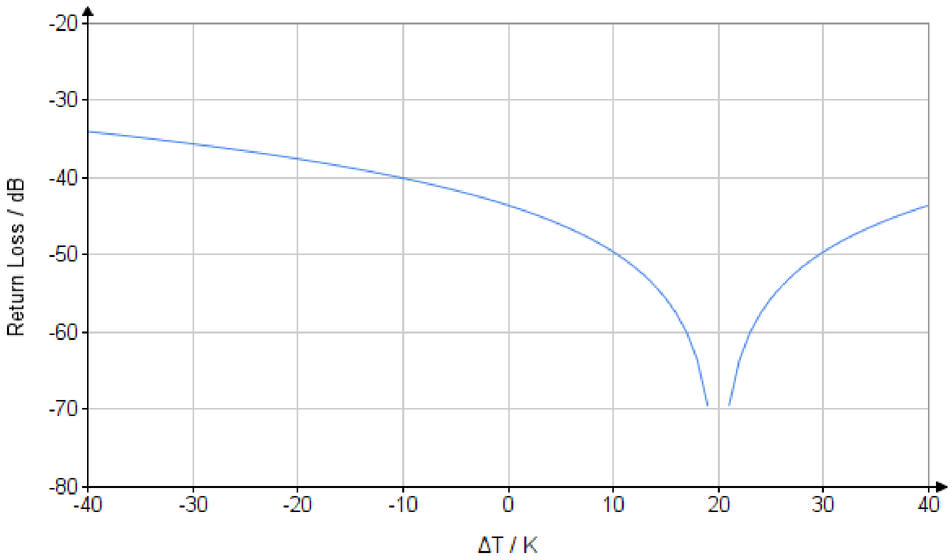


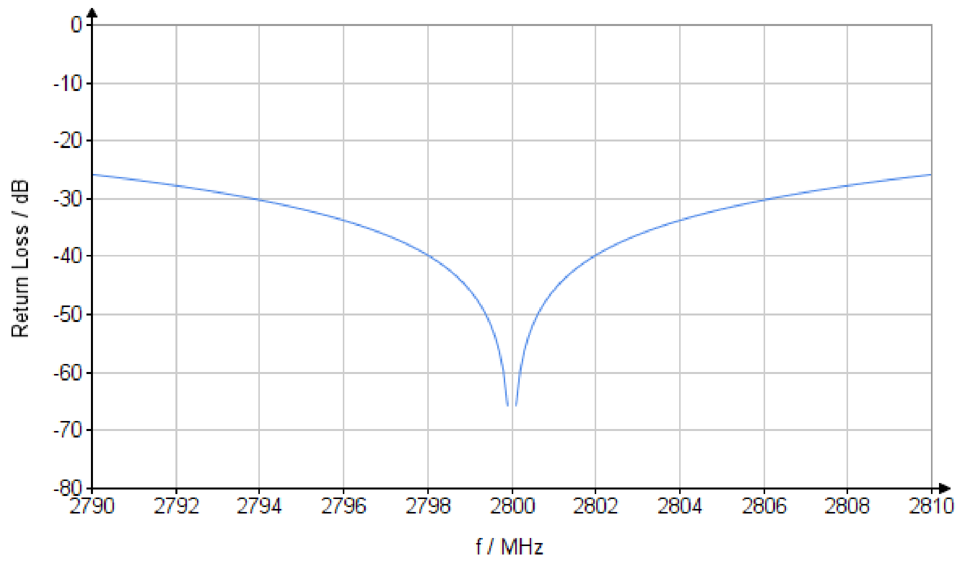
Matching Frequency: 2800 MHz
Matching Temperature: 20 °C
Waveguide Length: 10 m

Horizontal Port	OMT Return Loss: -18 dB	OMT Mismatch Phase: 0
Vertical Port	OMT Return Loss: -18 dB	OMT Mismatch Phase: 3π/2

CALCULATION OF THE ZDR BIAS CAUSED BY DIFFERENT RETURN LOSSES

Short Distance between mismatched load and tuner





Matching Frequency: 2800 MHz

Matching Temperature: 20 °C

Waveguide Length: 0.5 m

Horizontal Port — OMT Return Loss: -18 dB — OMT Mismatch Phase: 0

Vertical Port — OMT Return Loss: -18 dB — OMT Mismatch Phase: 3π/2

TUNING OF THE ANTENNA WAVEGUIDE / OMT

Design the system in a way that a tuner can be placed as close to the OMT as possible

Measure the temperature coefficient of both (horizontal and vertical polarization) antenna waveguides

- Connect the VNA to the reference plane input port of the respective antenna waveguide
- Measure the reflection coefficient S_{11}
- Set the markers to one or two distinct notches and measure the frequency of the notches
- Wait until the outdoor temperature has changed by at least 10°C
- Repeat the measurement of the frequencies of the notches
- Calculate the temperature coefficient $\frac{\Delta f}{\Delta T} = \frac{f_{notch}(T_{hot}) - f_{notch}(T_{cold})}{T_{hot} - T_{cold}}$ Note that the coefficient is always negative!

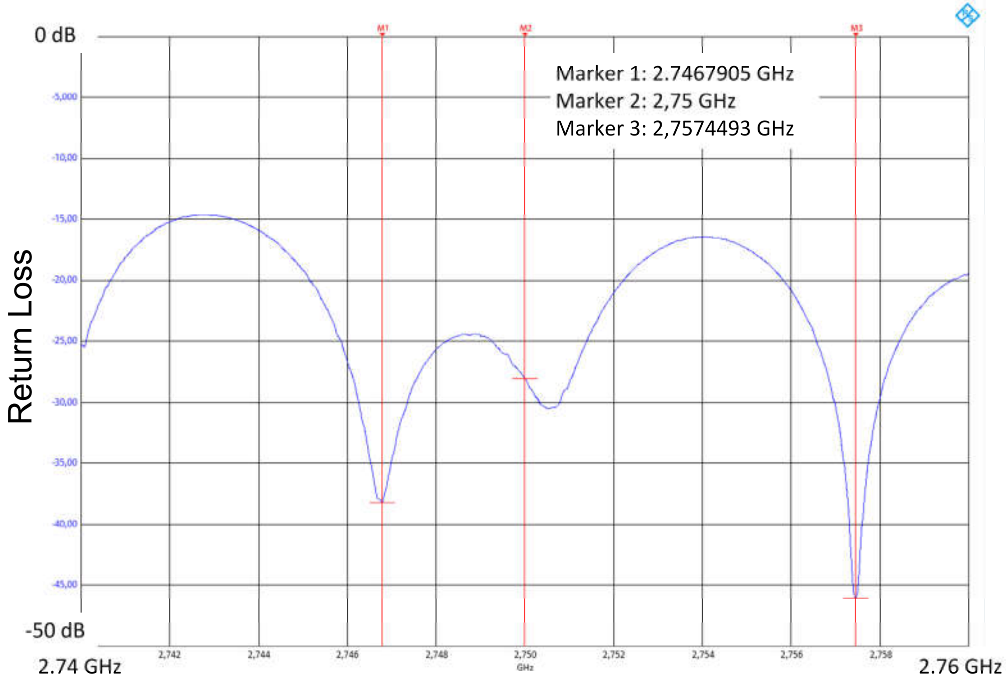
Calculate the high frequency limit of the tuning interval $f_{high} = f + \frac{\Delta f}{\Delta T}(T - T_{high})$ T: Temperature during tuning, T_{high}: Max. operating outdoor temperature

Calculate the high frequency limit of the tuning interval $f_{low} = f + \frac{\Delta f}{\Delta T}(T - T_{low})$ T_{low}: Min. operating outdoor temperature

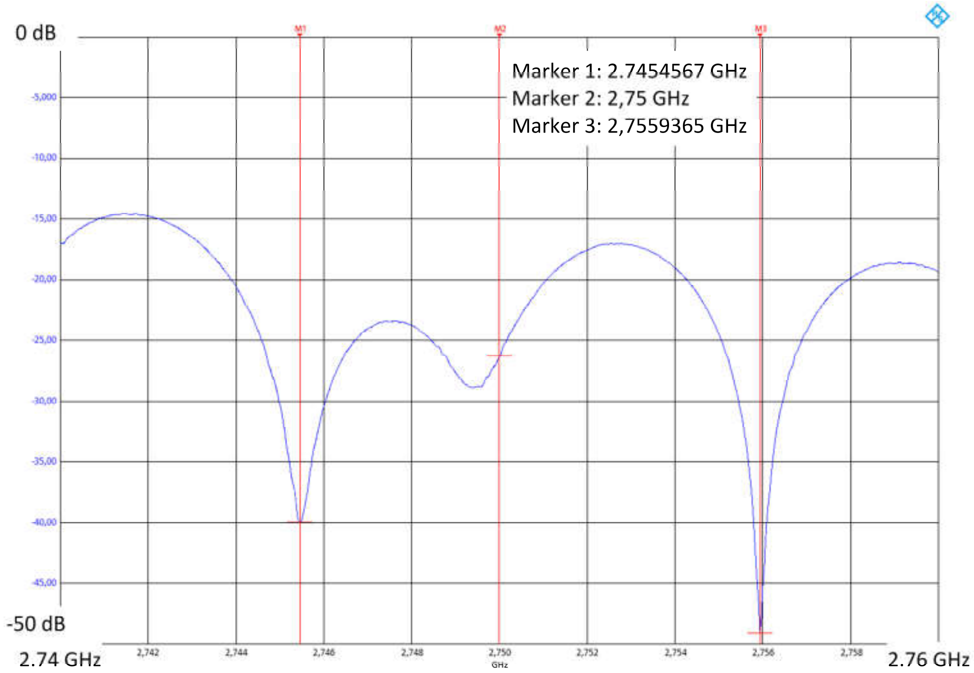
Tune the waveguide using the VNA display as reference (Set the markers of the VNA to the frequency limits)

MEASUREMENT OF THE TEMPERATURE COEFFICIENT

T_{cold} = 24.8 °C
F_{notch} = 2.7574493 GHz



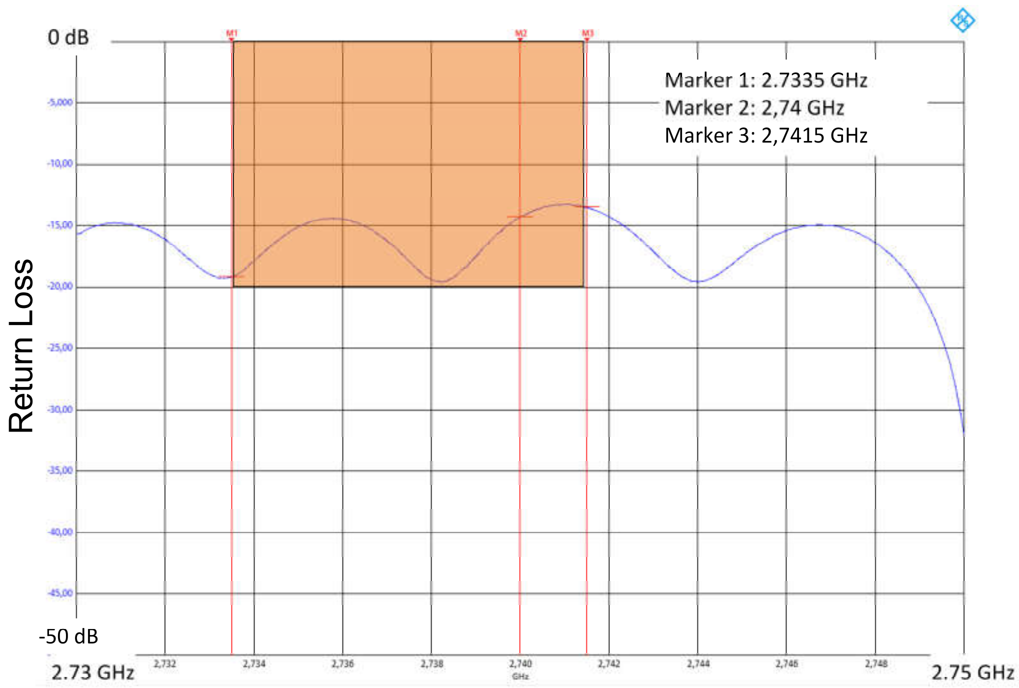
T_{hot} = 34.8 °C
F_{notch} = 2.7559365 GHz



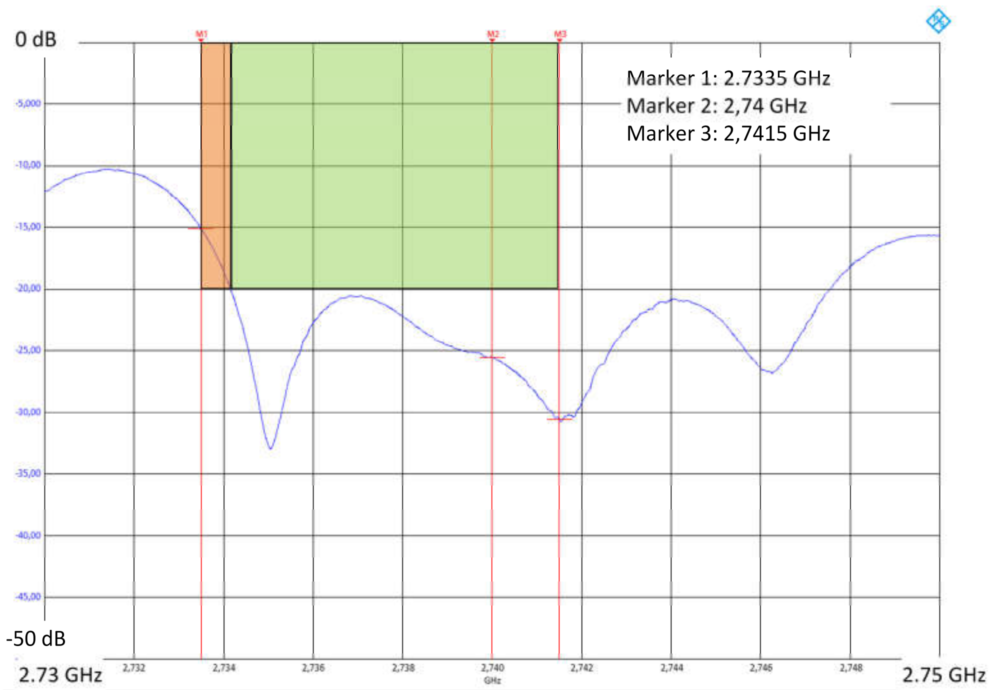
Temperature coefficient $\Delta F/\Delta T$ = -151 kHz/°C

TUNING OF HORIZONTAL POLARIZATION ANTENNA WAVEGUIDE

Tuning temperature: 25 °C
Temperature coefficient: 100 kHz/°C
Radar frequency: 2.74 GHz

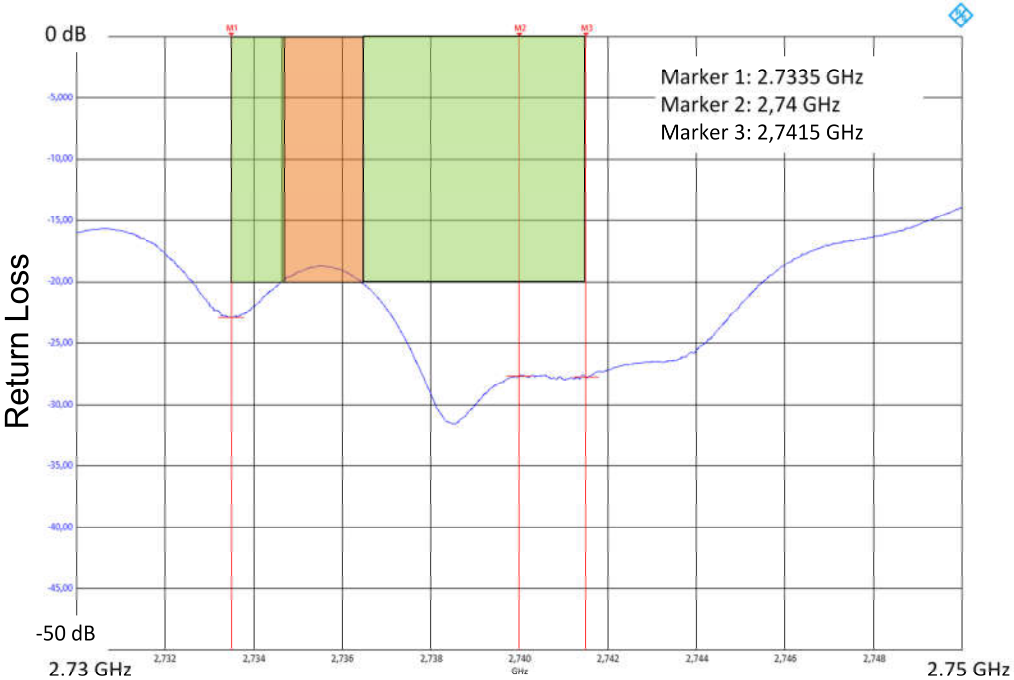


Outdoor operating temperature: -40 °C - +40 °C
Tuning frequency interval 2.7335 GHz – 2,7415 GHz

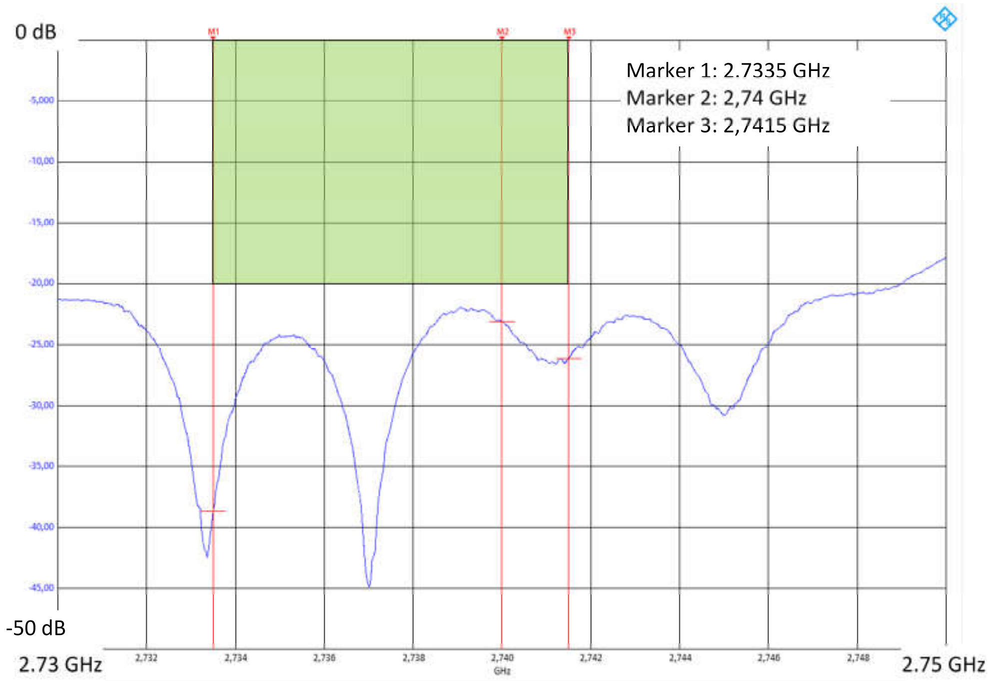


TUNING OF VERTICAL POLARIZATION ANTENNA WAVEGUIDE

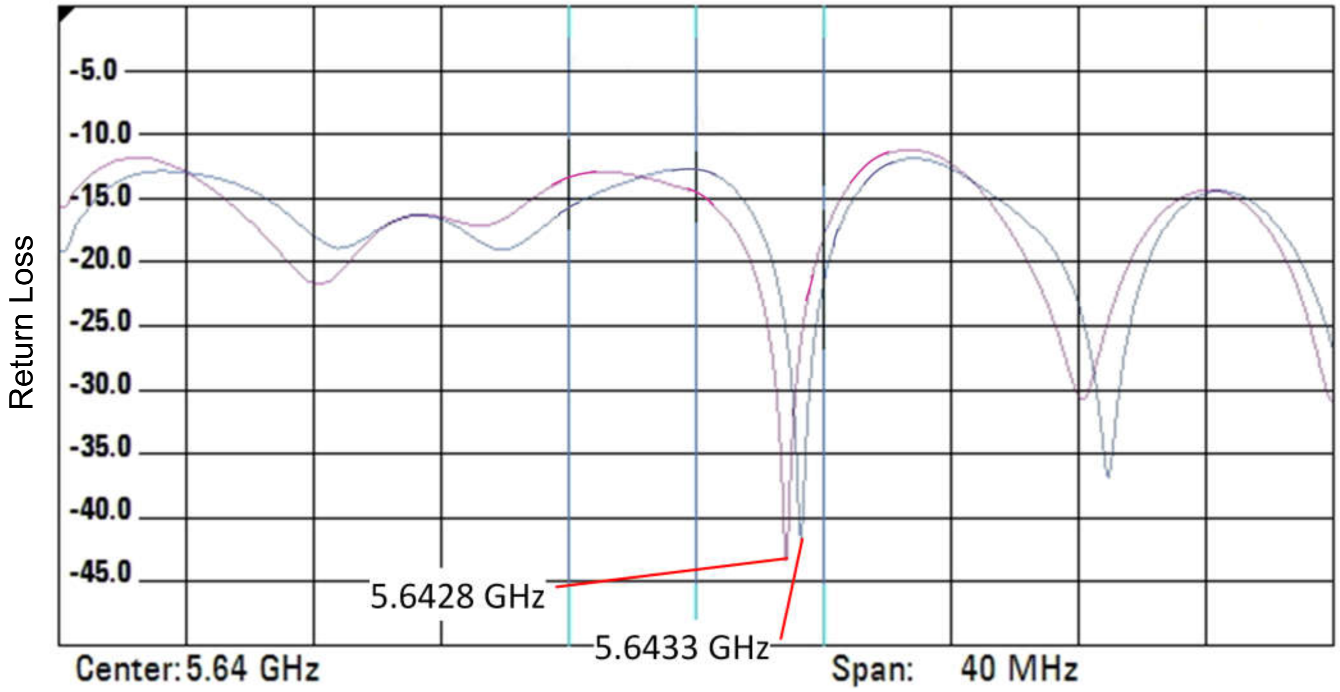
Tuning temperature: 25 °C
Temperature coefficient: 100 kHz/°C
Radar frequency: 2.74 GHz



Outdoor operating temperature: -40 °C - +40 °C
Tuning frequency interval 2.7335 GHz – 2,7415 GHz



PRESSURE DEPENDENCE WAVEGUIDE MATCHING



From Virgile: Deflection of Waveguide Subjected to Internal Pressure (5)

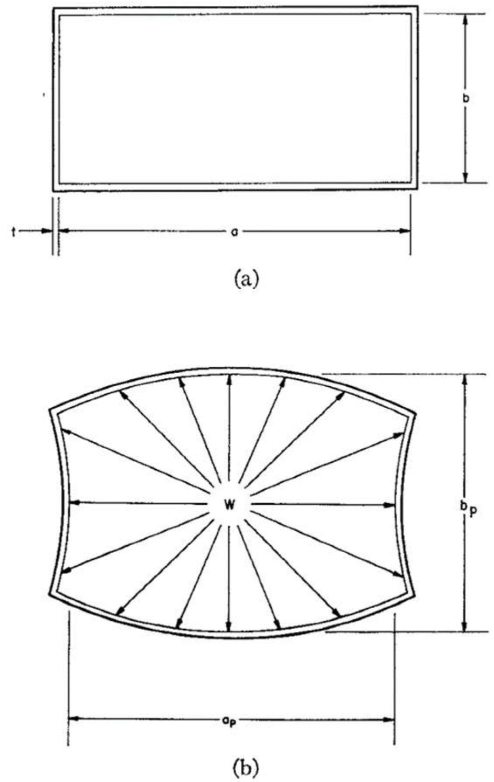


Fig. 1—(a) Unpressurized waveguide; (b) waveguide under pressure.

PRESSURE DEPENDENCE WAVEGUIDE MATCHING

Parameters

f(0 mbar) = 5.6428 GHz

f(30 kPa) = 5.6433 GHz

a(0 mbar) = 47.55 mm (WR187)

b = 22.15 mm (WR187)

t = 1.626 mm (WR187)

E = 69 GPa Young's Modulus for Al

w = 30 kPa waveguide pressure

Calculation based on resonance frequency

Resonance frequencies of a TE10n cavity:

$$f_r = \frac{c}{2\pi}\sqrt{\left(\frac{\pi}{a(p)}\right)^2 + L^2}$$

Calculate L^2 using f(0 mbar) and a(0 mbar)

Calculate a(430 mbar) using f(430 mbar) and L^2

∆a = a(30kPa) – a = -13.5 µm

Calculation based on deflection theory

From Virgile: Deflection of Waveguide Subjected to Internal Pressure (5):

$$y_b = \frac{w}{E}\left(\frac{5}{32}\frac{b^4}{t^3} - \frac{b^2(a^3+b^3)}{8(a+b)t^3}\right)$$

$$a_p = a + 2y_b, \;\; \Delta a = a_p - a$$

∆a = 13.46 µm

SUMMARY

ZDR bias variations can be caused by:

- Temperature variations of the antenna waveguide circuit
- Transmitter frequency drift or modulation
- Variation of the waveguide pressure
- All parameters mentioned above affect the horizontal and vertical polarization antenna waveguide in the same manner. However due to slight differences in the length and residual mismatches of both waveguides the ZDR bias varies due to the variation of the transformation of these mismatches.

REFERENCES

(1) Frech, M.; Hubbert, J.: Monitoring the differential reflectivity and receiver calibration of the German polarimetric weather radar network, Atmos. Meas. Tech., vol. 13, 2020, p. 1051–1069

(2) Hubbert, J.C.: Differential Reflectivity Calibration and Antenna Temperature, J. Atmos. Oceanic Technol. vol. 34, 2017, p. 1885 - 1906

(3) Pozar, D.M.: Microwave Engineering, 3rd Ed., John Wiley & Sons, New Jersey, 2005, Ch. 6.3

(4) Pozar, op.cit. Ch. 2.3

(5) Virgile, L.G.: Deflection of Waveguide Subjected to Internal Pressure, IRE Trans. Microw. Theory Tech., 1957 p. 247 - 250

Leonardo INTERNATIONAL

Thank you for your attention!

Frank Gekat

f.gekat@leonardogermany.com

LEONARDO Germany GmbH
Raiffeisenstrasse 10
41470 Neuss, Germany
Tel: +49 (0) 2137 782-0
info@leonardogermany.com
www.leonardogermany.com