

CHARACTERIZATION OF FERRITES AT LOW TEMPERATURE AND HIGH FREQUENCY

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1. Why the load at low temperature?

- **Broadband HOM damping in high current storage ring has been achieved by using beam-pipe ferrite loads, located at room temperature in spite of usage of a superconducting cavity (Cornell, CESR-B).**
- **Adopting the same damping concept for the ERL with absorbers between the cavities in a cavity string will require operating the absorbers at a temperature of about 80 K.**
- ***This temperature is high enough to intercept HOM power with good cryogenic efficiency, and is low enough to simplify the thermal transition to the cavities at 2 K.***
- **However, the electromagnetic properties of possible absorber materials were not well known at cryogenic temperatures.**
- **Therefore, we performed a measurement program at Cornell to find possible absorbers for HOMs in the ERL.**

2. Materials

- We examined 10 different materials listed in the Table. Not all of them were measured in the whole frequency range because of absence of some samples with the necessary shape, they are marked “minus” (-) in the Table. Some materials appeared to be very brittle (C48-E1, C48-E2) and cannot be recommended for further usage in our project.

Freq., GHz	1-12.4	12.4-18	18-26.5	26.5-40	The tested materials fall into 3 groups: ferrites TT2-111R, C48-E1, C48-E2, hexagonal phase ferrites M1, M2, M3, and MZ [Trans-Tech Inc., Countis Laboratories], and Ceradyne ceramics [Ceradyne Inc.]
Material					
TT2-111R	+	+	+	+	
C48-E1	+	-	+	+	
C48-E2	+	-	+	+	
HexM1	+	+	+	+	
HexM2	+	+	+	+	
HexM3	+	+	+	+	
HexMZ	+	+	+	+	
ZR10CB5	-	+	+	+	
ZR20CB5	-	+	+	+	
Z7YL	-	+	+	+	

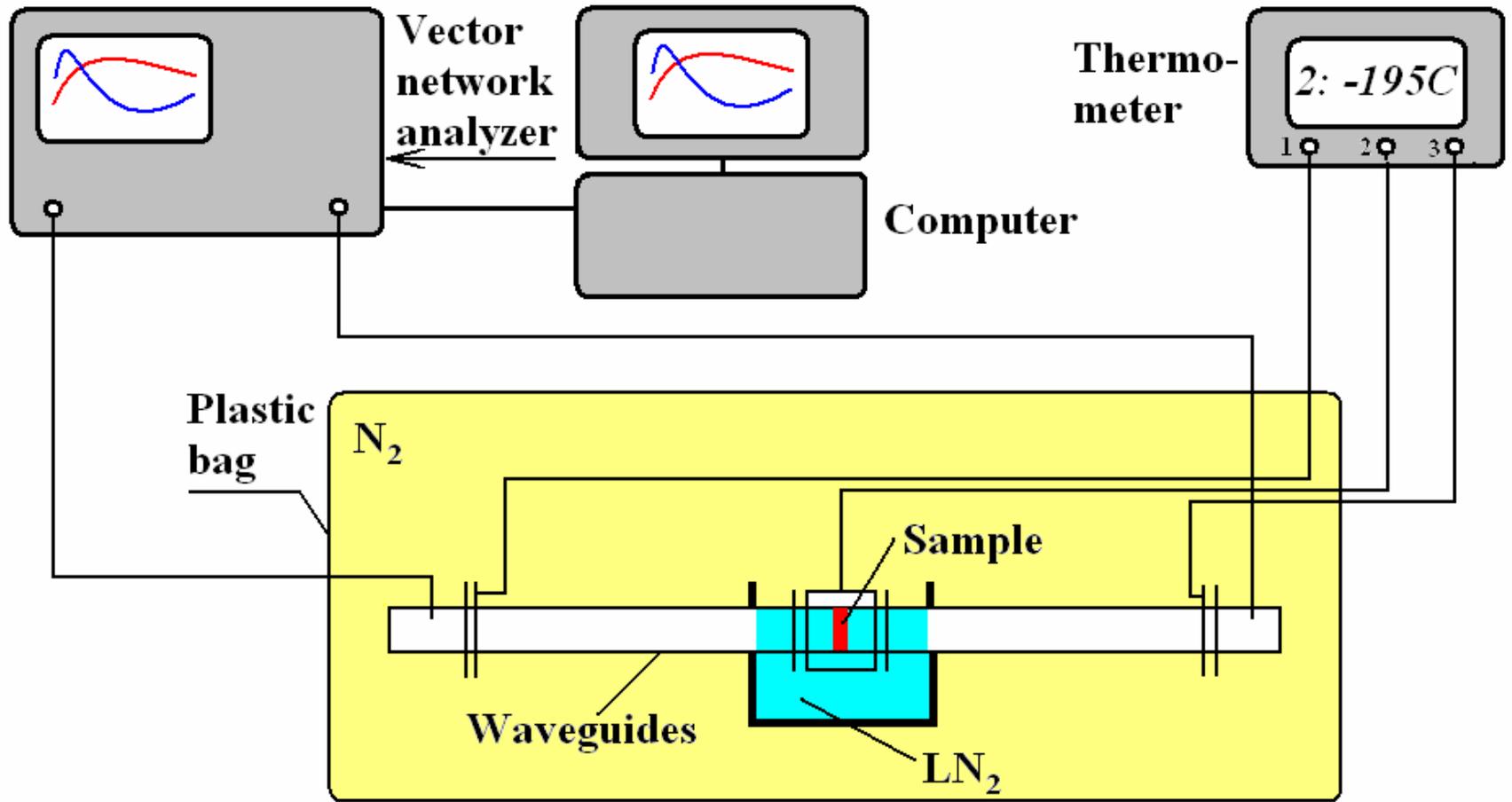
3. Measurements

- If part of a transmission line is filled with the material, measurement of the complex reflection and transmission coefficients at the frequency of interest with a network analyzer gives data for calculation of complex permittivity, ϵ , and complex permeability, μ , of the sample.
- It is convenient if the thickness of the sample is less than $L/2$ to avoid the resonance and to decrease the errors.
- For measurements below 12.4 GHz a coaxial line, 7/3.05 mm, was used, with the HP8720 network analyzer.
- Measurements in the region 12.4 – 40 GHz were done with Agilent 8722ES with waveguides: WR62 (12.4 – 18 GHz), WR42 (18 – 26.5 GHz), and WR28 (26.5 – 40 GHz).
- Measurements in this region (12.4 – 40) were partly repeated with the analyzer Agilent E8363B, and some results were substantially improved.
- We used the **TRL** calibration as giving the most accurate results of measurements. This calibration involves measurements of **THRU** signals between 2 waveguides, **REFLECTION** (short) standard measurement, and a measurement of a **LINE** between two w/g terminals.
- The procedure of calibration became more complicated because for measurements of standards, it was necessary to cool the w/g line down, make measurement, warm it up, connect the next standard and so on.

3.1. Measurements. Transmission lines used for 4 frequency ranges.



3.2. Schematic of measurements

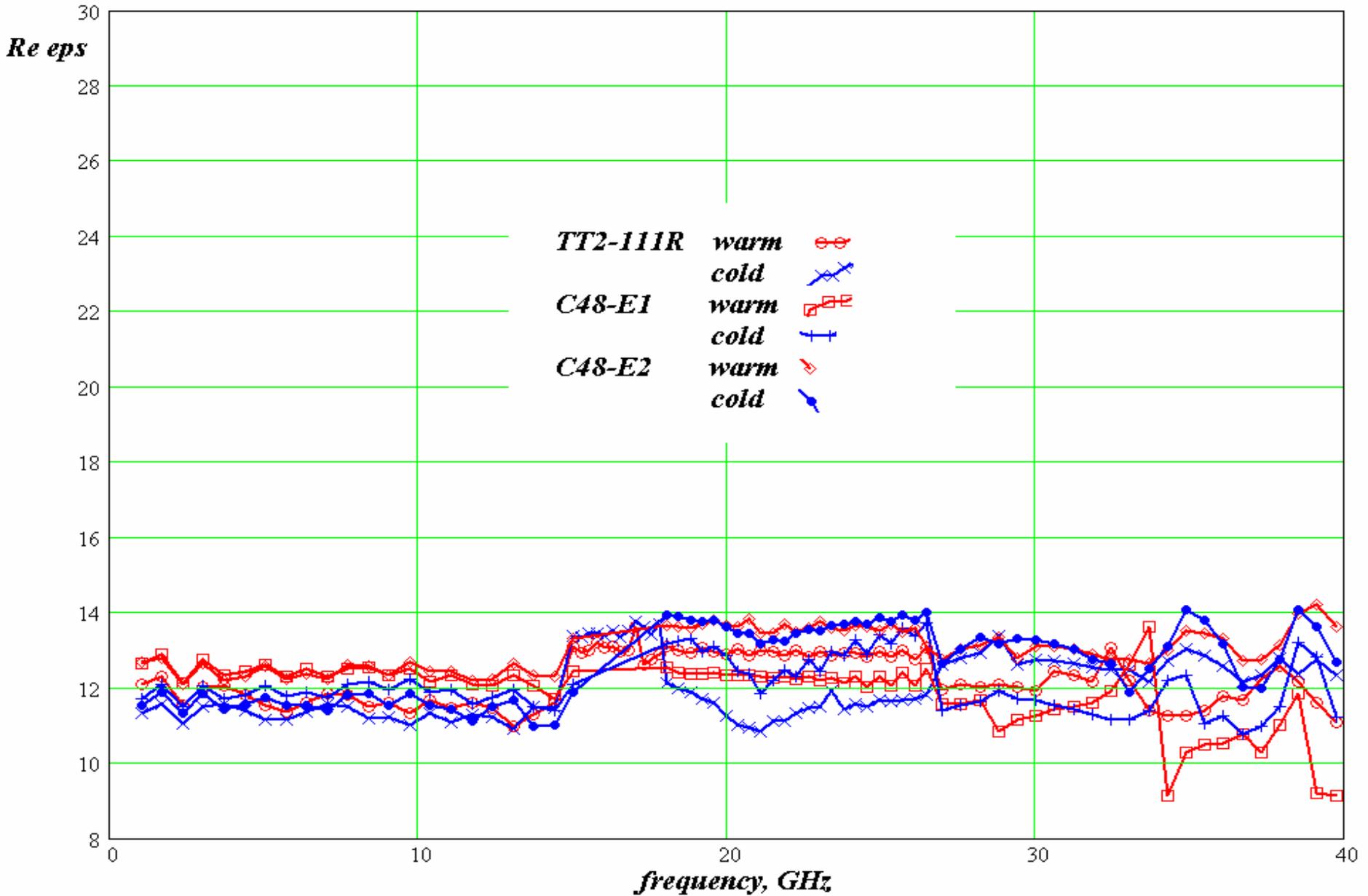


3.3. Measurements (some details)

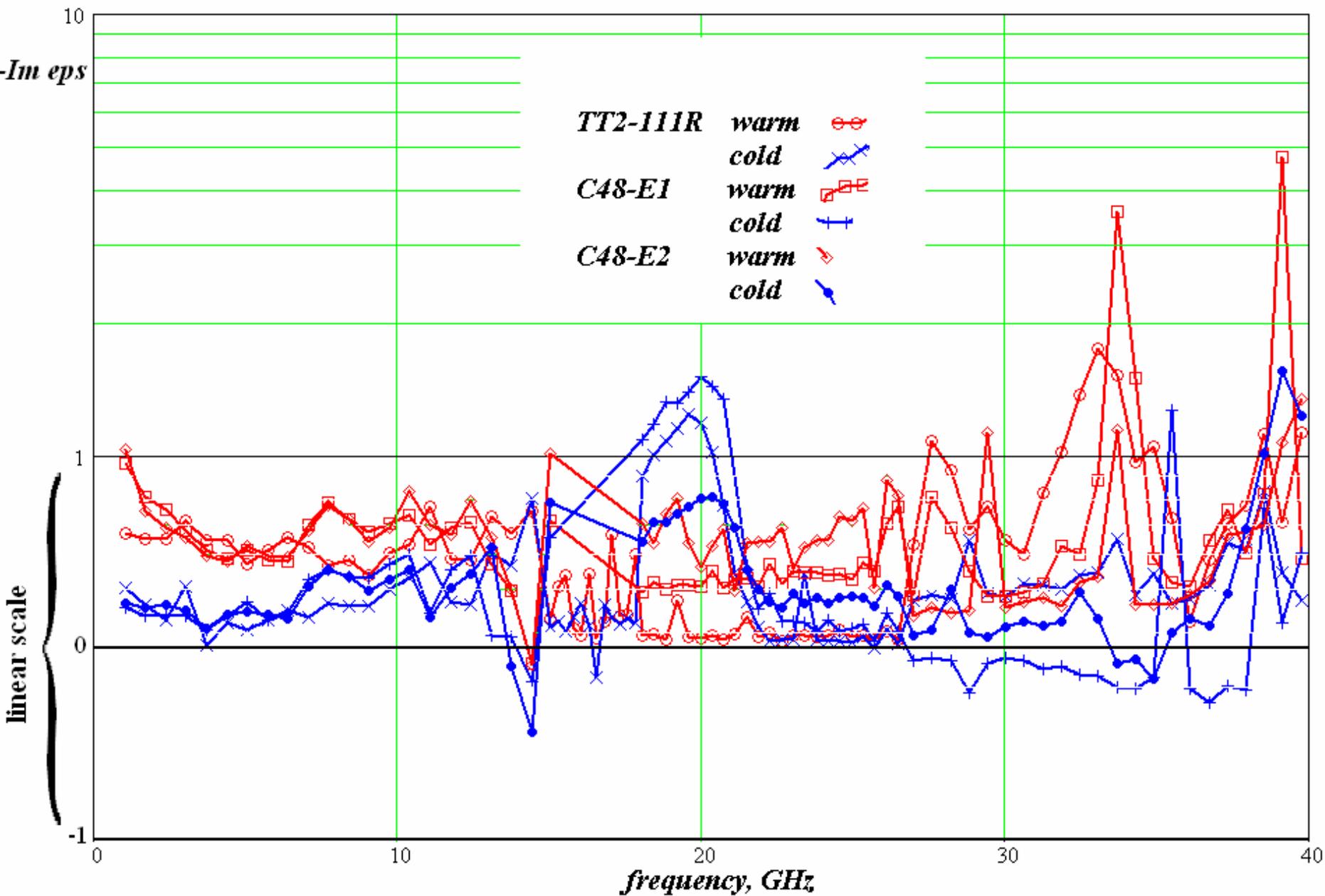
- **Changes of the line length and change of dielectric constant of N₂ were taken into account.**
- **A plastic bag was used to prevent condensation of moisture on the cold parts (water has $\epsilon \sim 80!$).**
- **Small holes in the w/guides are needed because after non-equal from different sides pressure drop, when cooling down, the sample moves in the w/g like a piston.**
- **Temperature of the Sample Holder and coaxial line- w/guide adapters was controlled by thermocouples.**
- **The surface of the LN₂ was seen to prevent spilling. If LN₂ is spilled, temperature of the ends drops and the error increases.**

4. Results (next 12 slides)

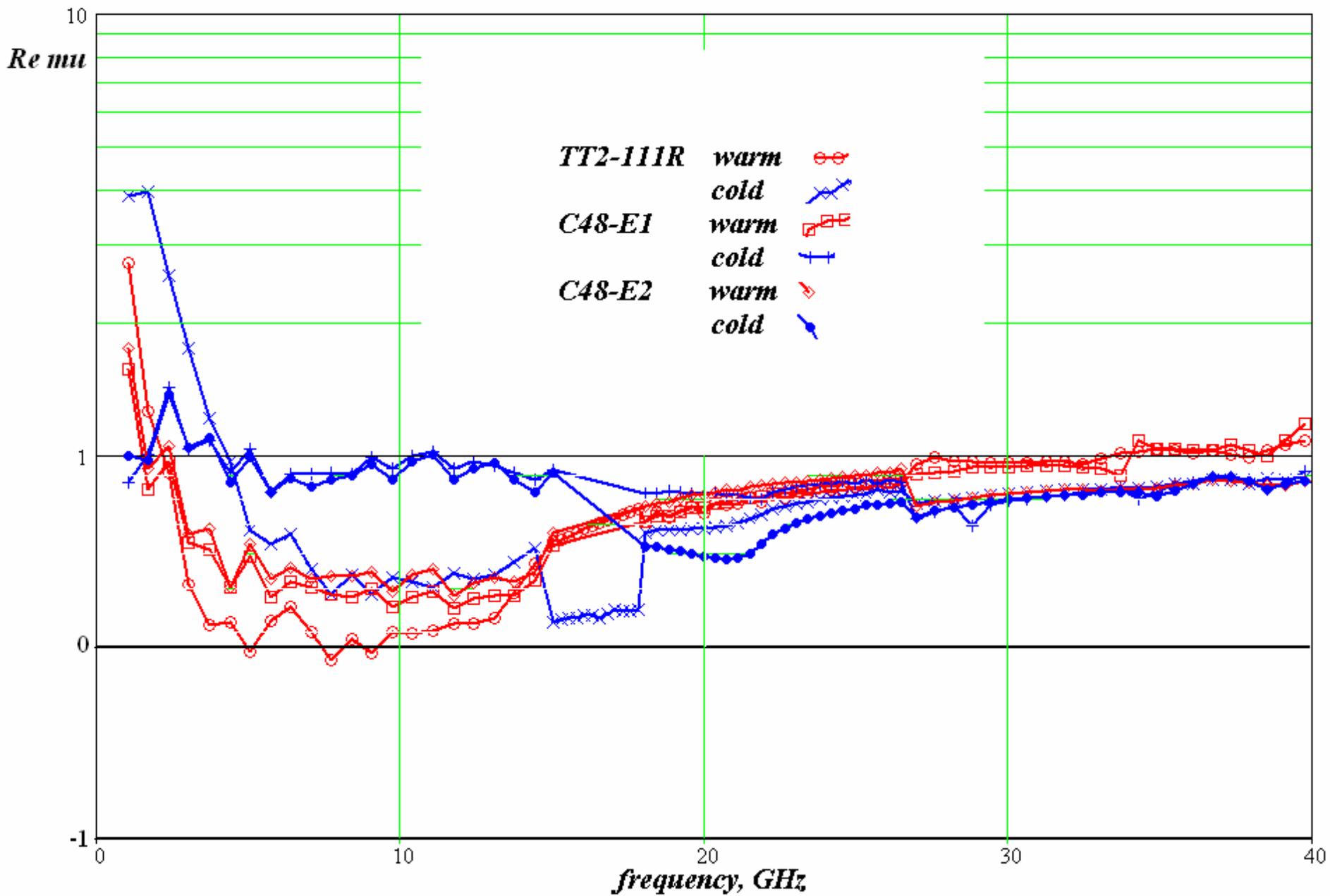
Real part of eps for ferrites of the first group within 1...40 GHz



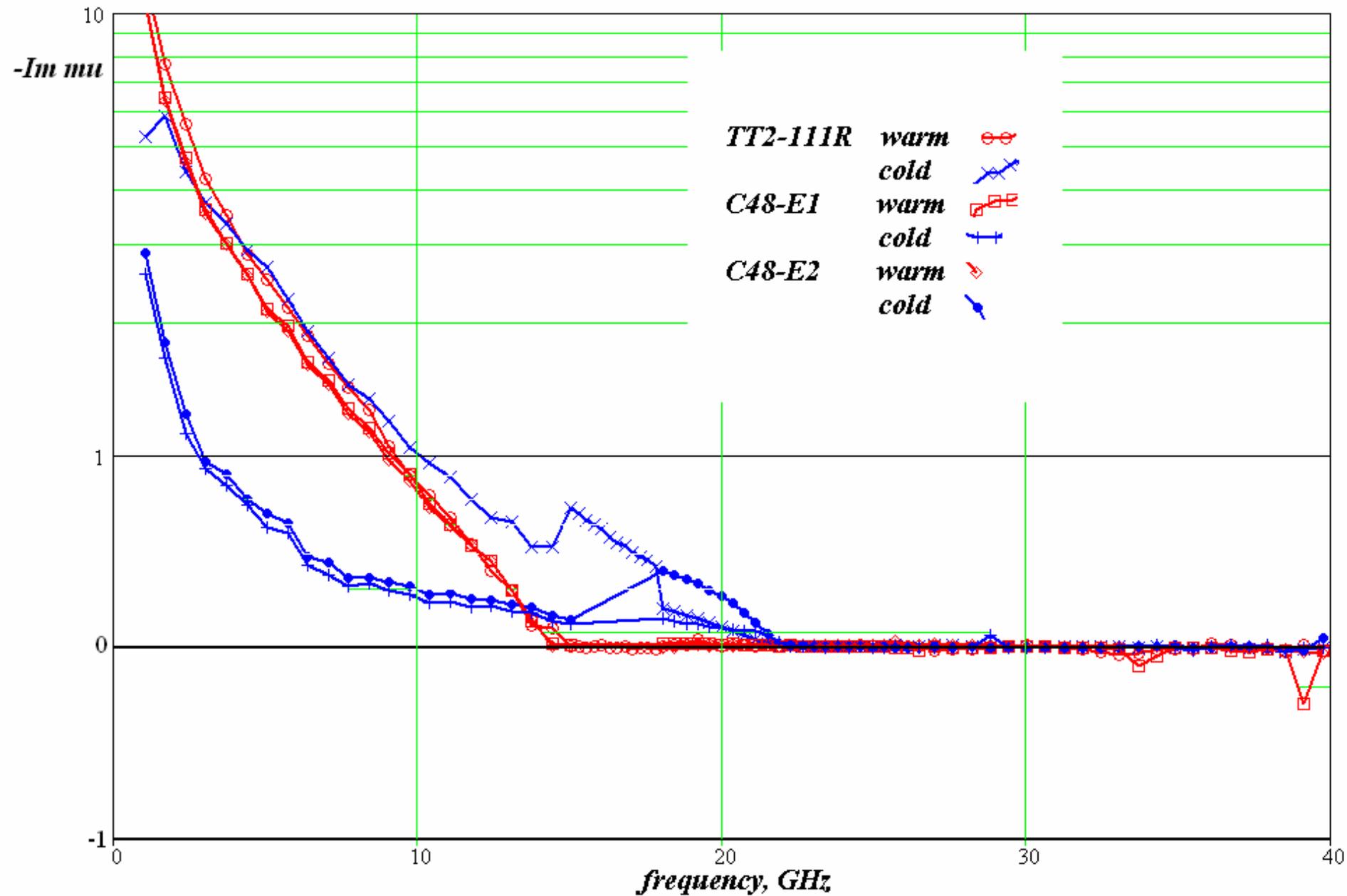
Imaginary part of eps for ferrites of the first group within 1...40 GHz



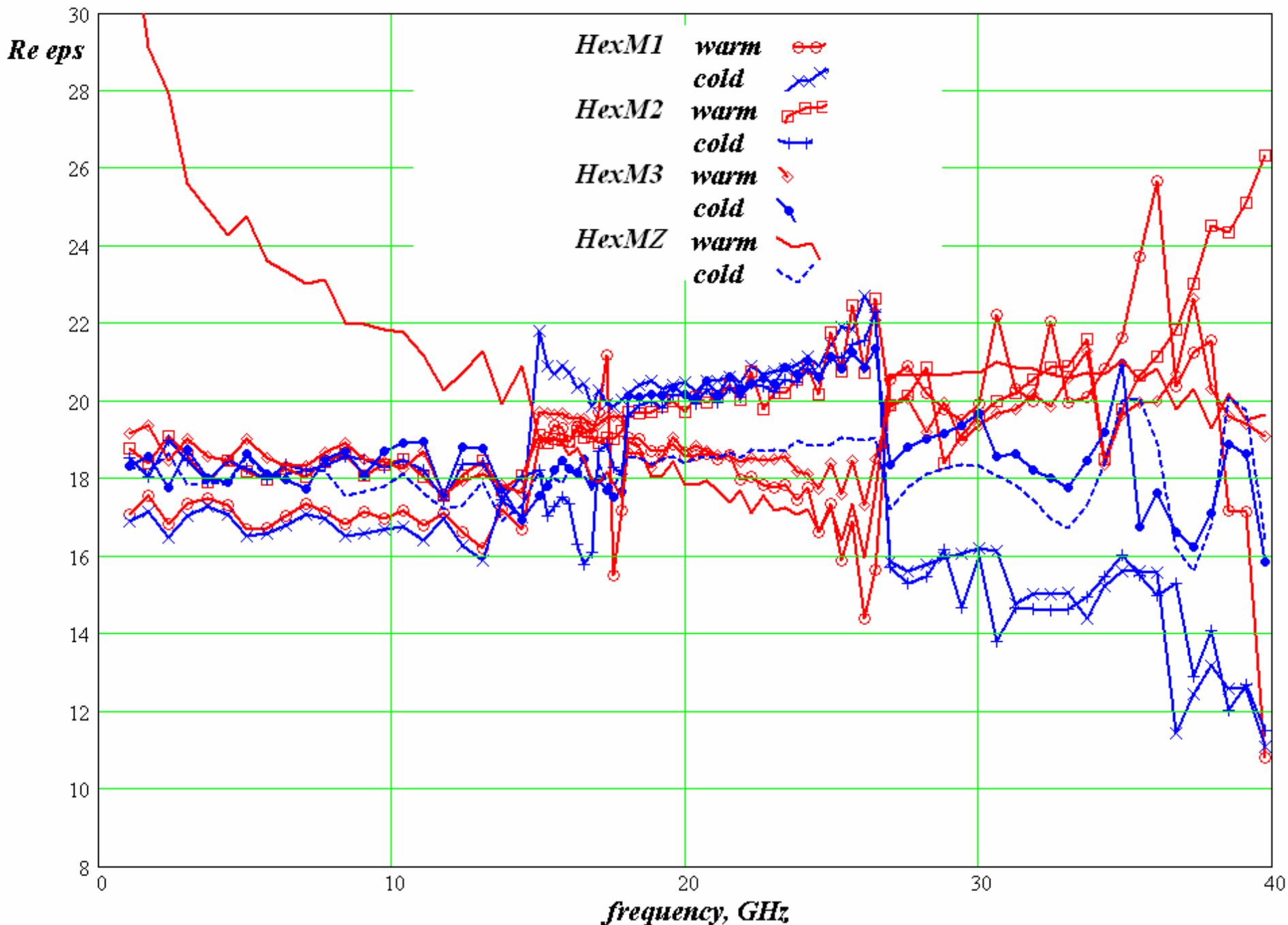
Real part of μ for ferrites of the first group within 1...40 GHz



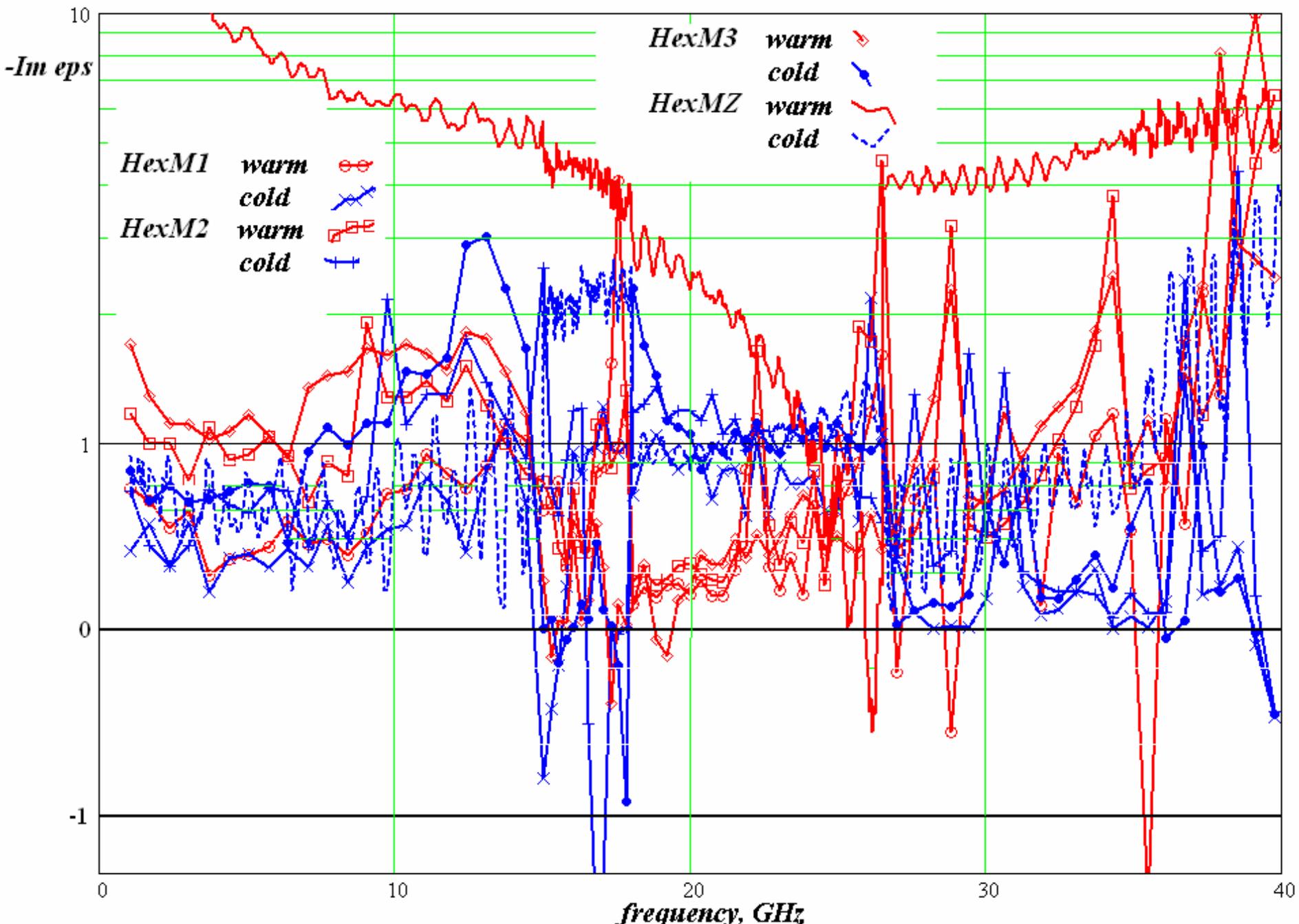
Imaginary part of mu for ferrites of the first group within 1...40 GHz



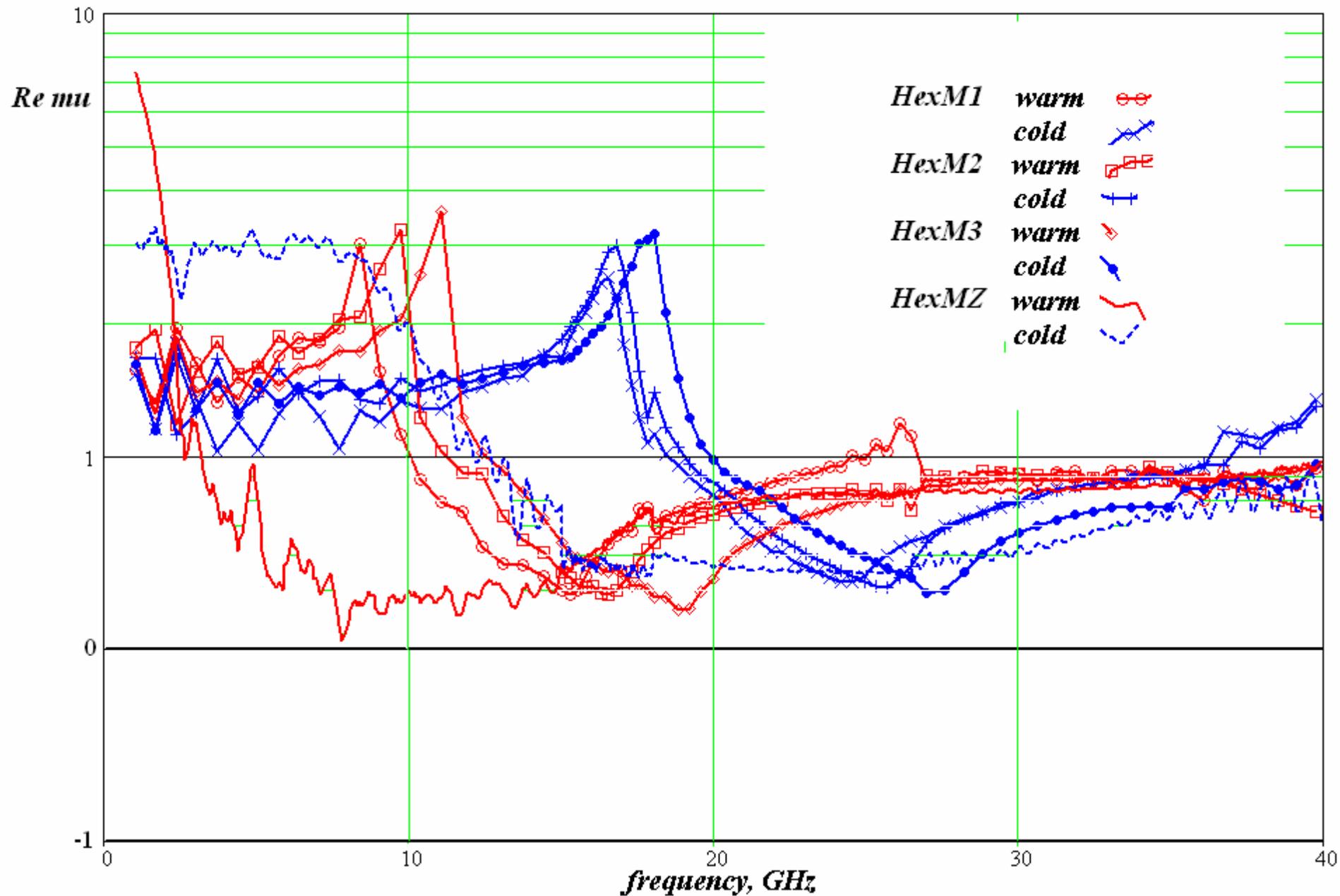
Real part of eps for Hexagonal ferrites within 1...40 GHz



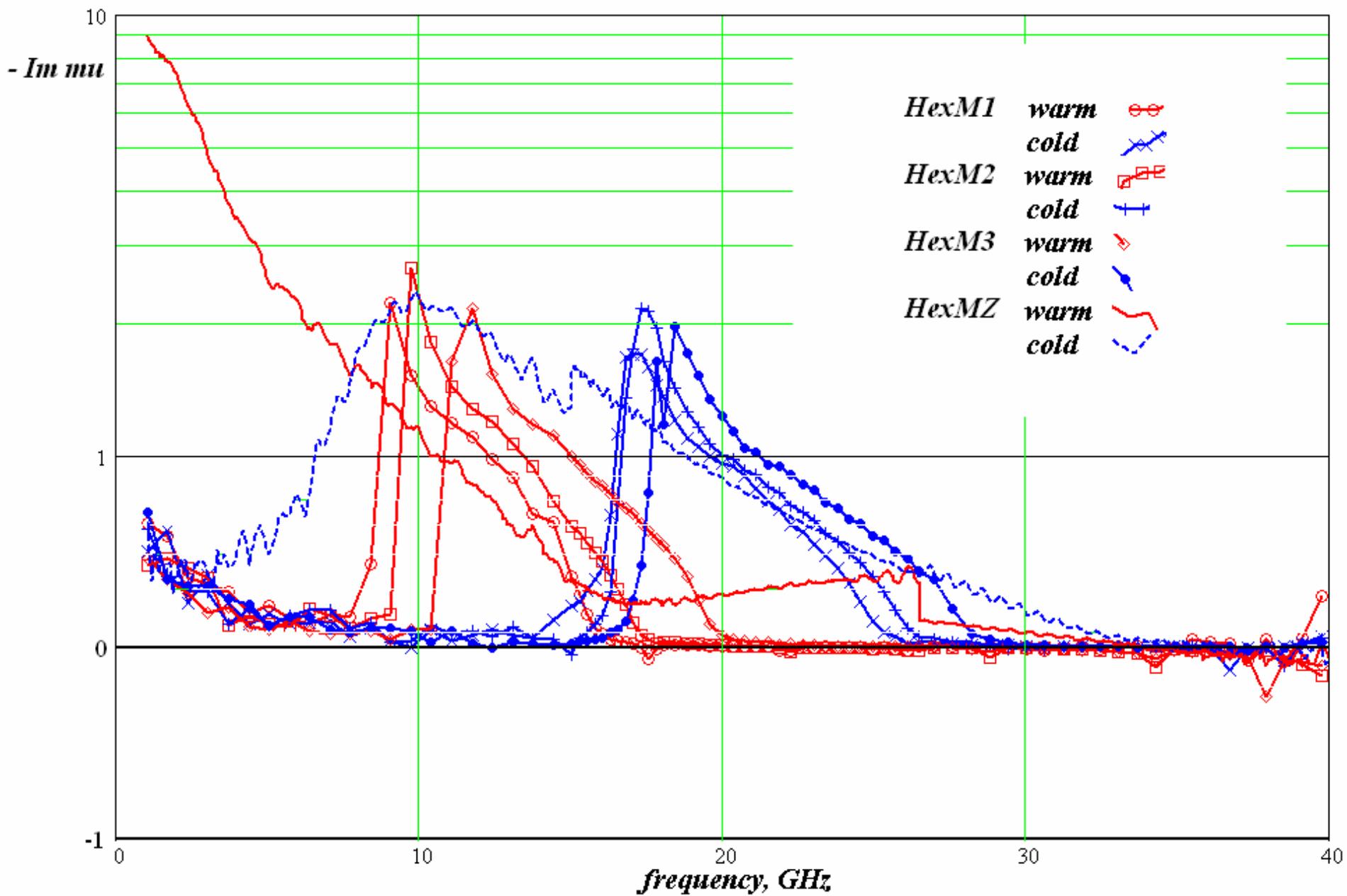
Imaginary part of eps for Hexagonal ferrites within 1...40 GHz



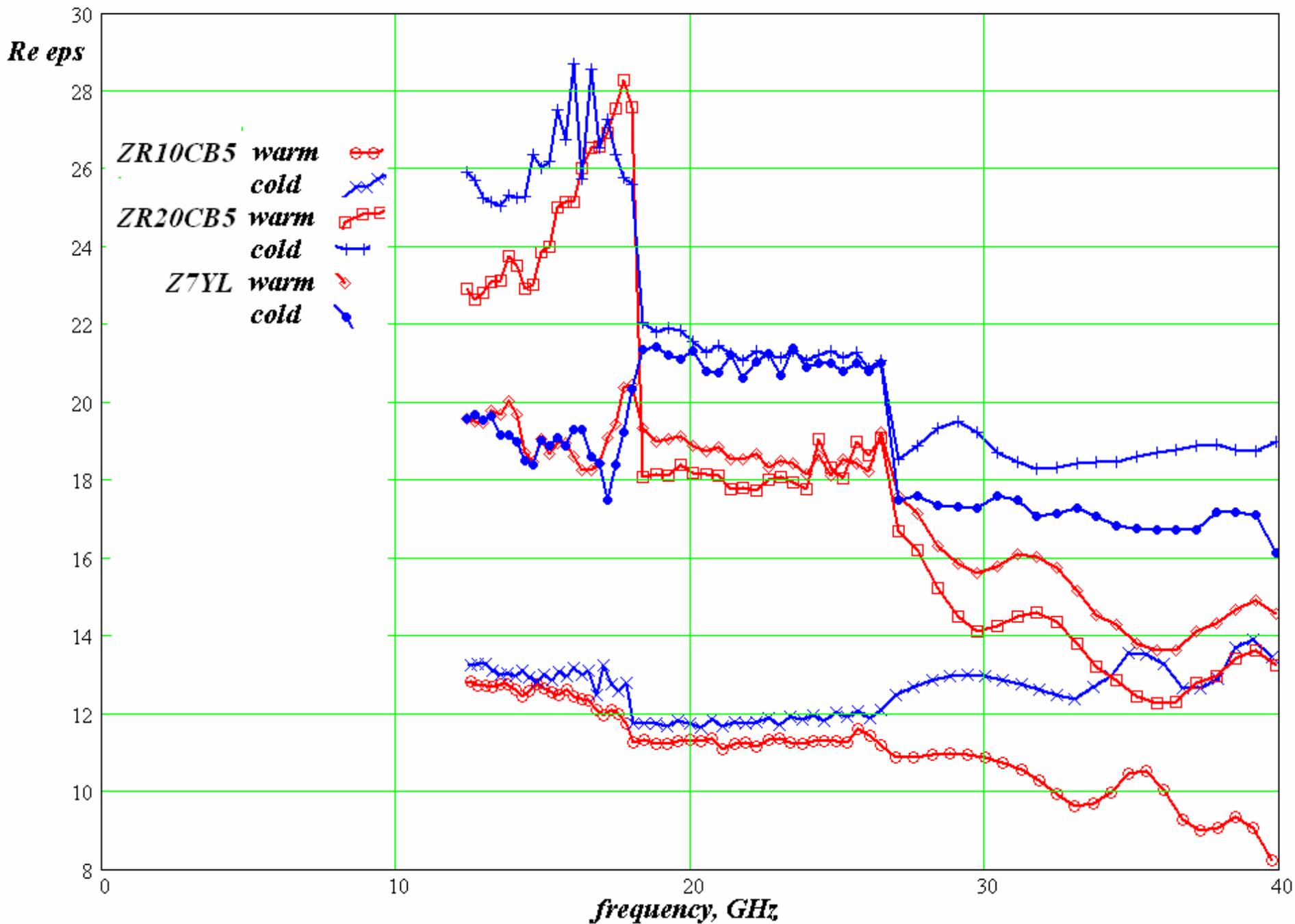
Real part of μ for Hexagonal ferrites within 1...40 GHz



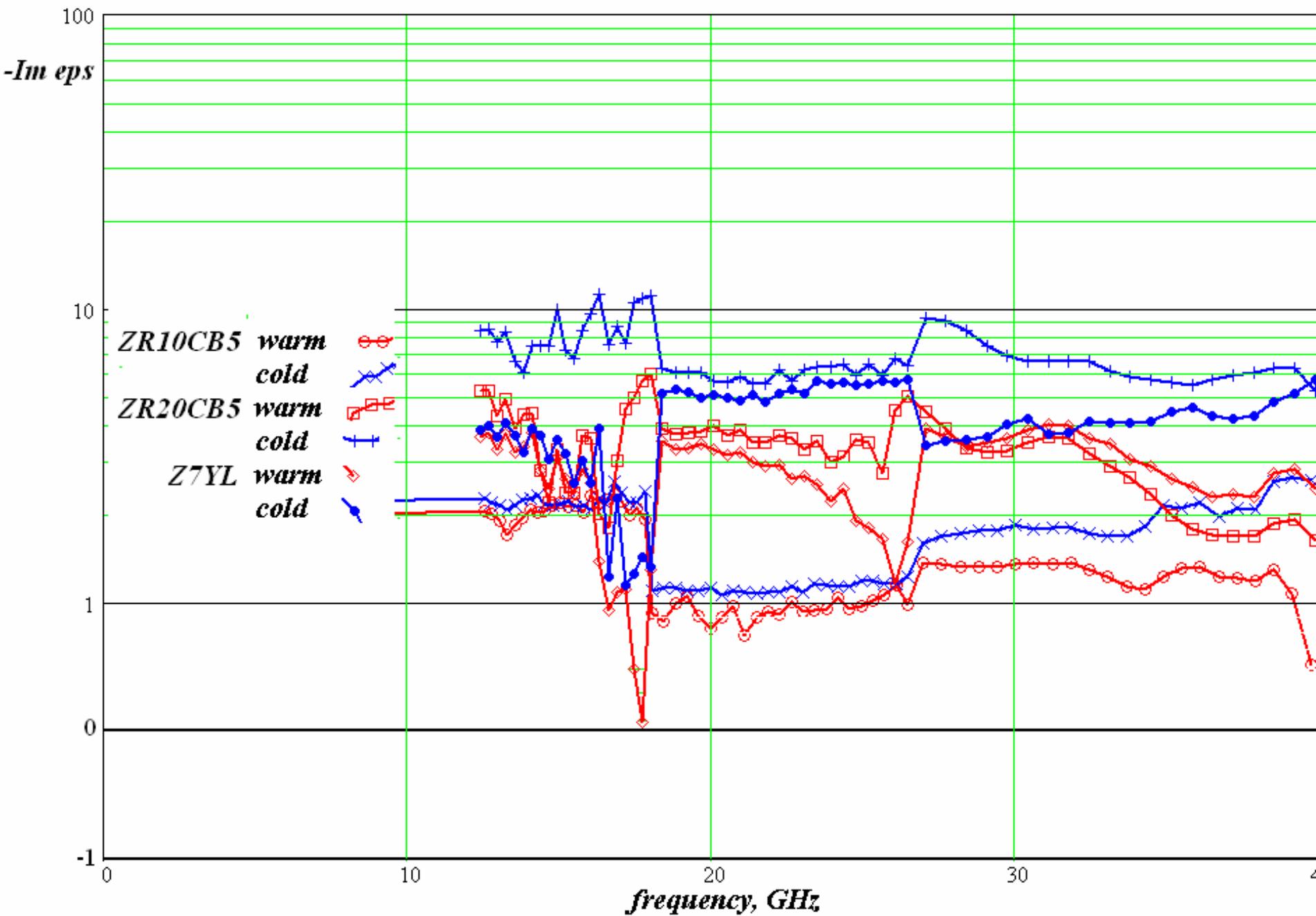
Imaginary part of μ for Hexagonal ferrites within 1...40 GHz



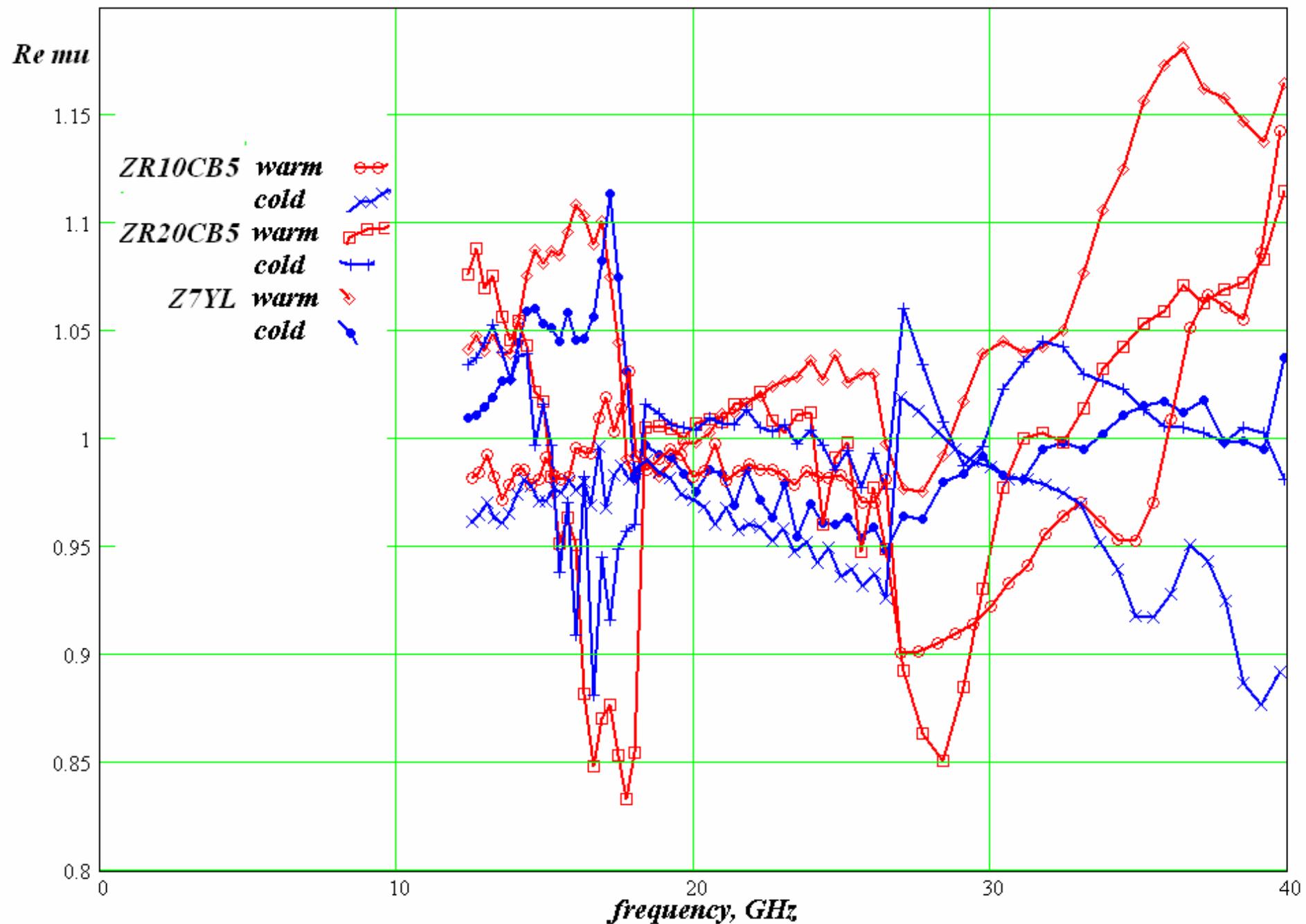
Real part of eps for Ceradynes within 12...40 GHz



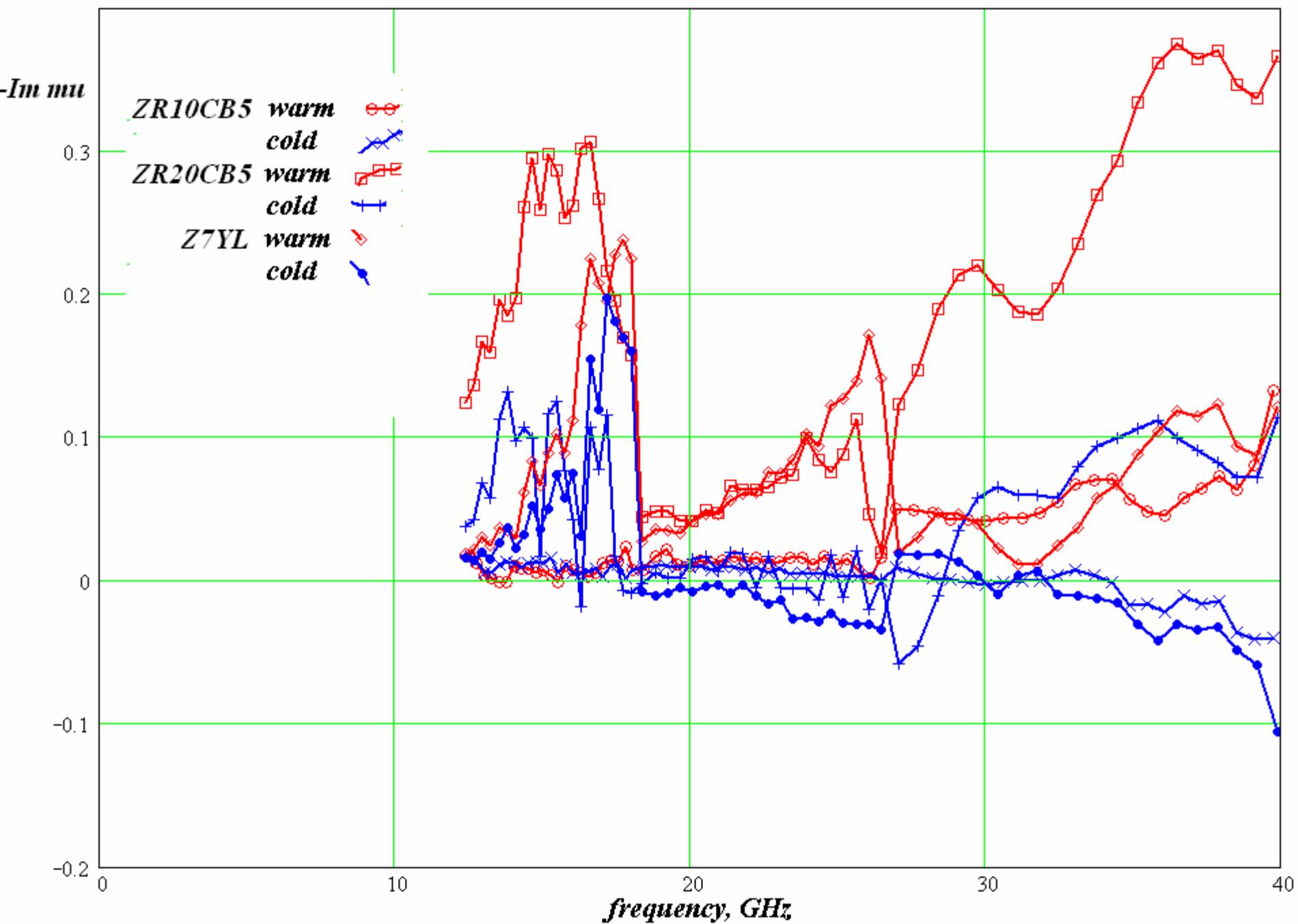
Imaginary part of eps for Ceradynes within 12...40 GHz



Real part of μ for Ceradynes within 12...40 GHz



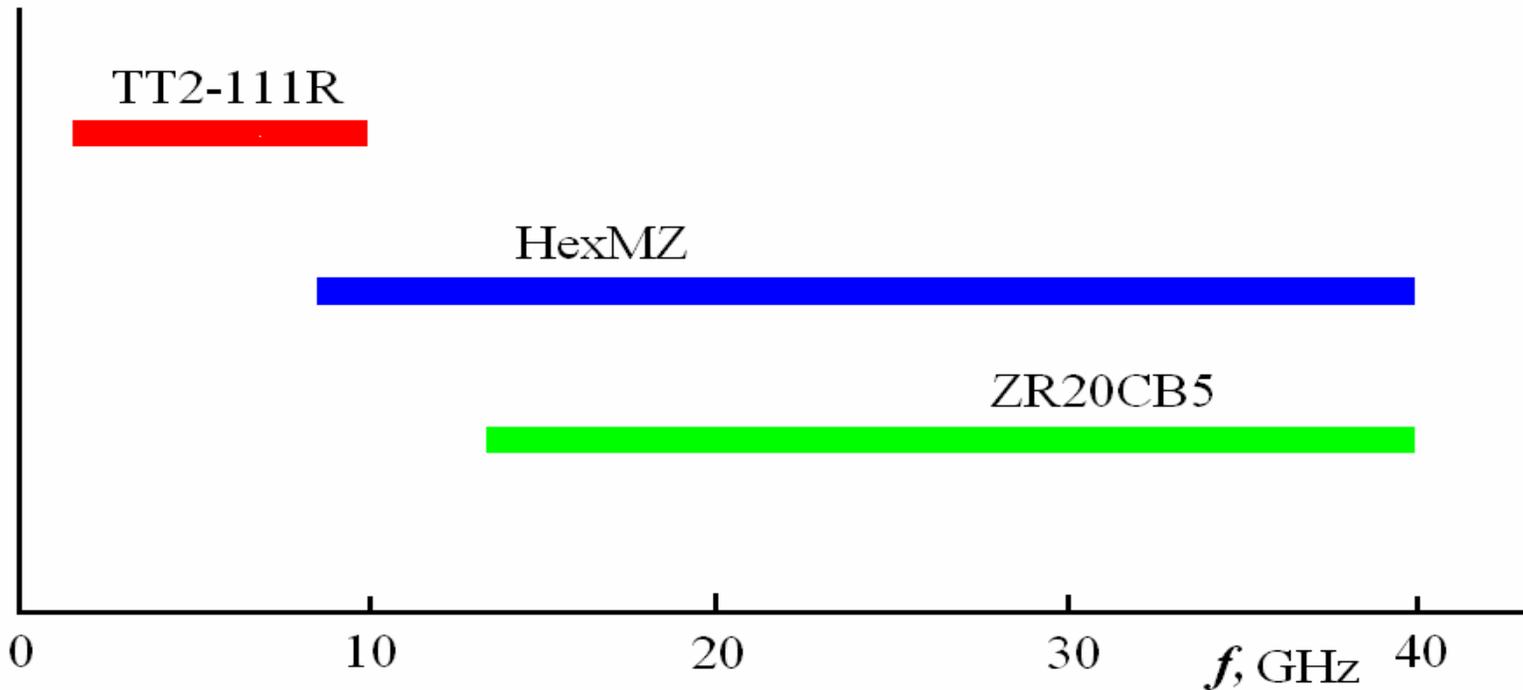
Imaginary part of mu for Ceradynes within 12 ...40 GHz



4.13. More about the results

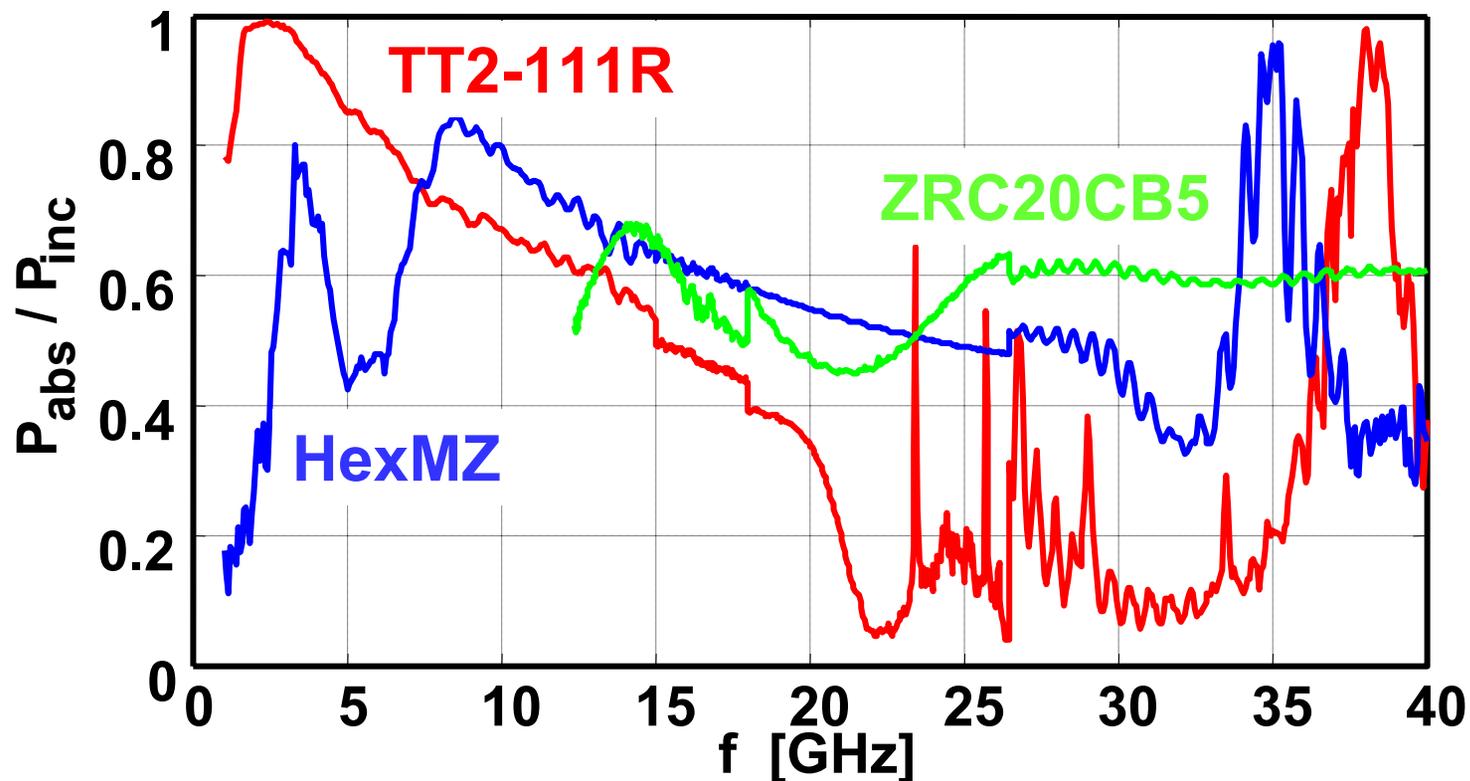
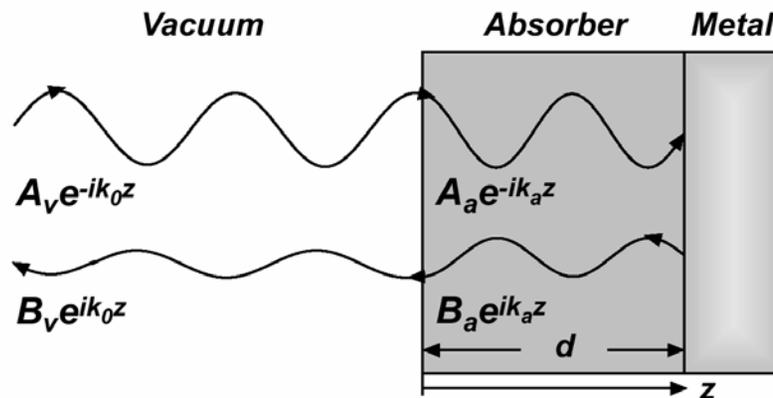
- The imaginary parts of both ϵ and m should be negative, this means that the material absorbs, not gives off, power. If our results show $Im \epsilon > 0$ or $Im m > 0$, this shows limits of our accuracy only.
- Same words about accuracy could be said for values $Im m \neq 0$, or $Re m \neq 1$ of Ceradynes.
- The vertical axis has for some graphs linear scale for values < 1 , and logarithmic for values > 1 . This provides a possibility to present data changing in a wide range and show the most significant details.
- Some errors can be caused by irregular shape of samples; it is hard to keep right shape and small gaps between samples and waveguide walls for so small sizes.
- Some data do not butt together at the ends of frequency ranges. Such a behavior was observed in data by M. Dohlus from DESY for ZR20CB5 and for other materials of this group at a room temperature. Different batches of the same material can have different properties.
- **However, now we have a general notion about the properties of examined materials and we have chosen the most promising of them for the cryogenic load.**

Regions of applications for 3 chosen materials



- Ferrite TT2-111R can be proposed as absorber at 80 K in the lower part of the frequency range, and ceramics ZR20CB5 can work in the mean and higher frequencies. In the mean frequencies 15 – 30 GHz both HexMZ and ZR20CB5 will complement each other because the losses in them are magnetic and electric, respectively. This should help to suppress different types of HOMs.

Absorber Model Calculation (d=3 mm) (based on measured ϵ and μ at 80 K)



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