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Using Smith Diagrams

In RF-technology, one often displays real and reactive impedances as a function of frequency in the form of a "focus". Figure 1 shows a typical example of this with an RF-transistor TDA 1087, and Figure 2 with a HB 9 CV-antenna. This article is to describe how to read Smith diagrams, and how to use them to advantage.

Every electronics technician knows that a series connection of real and reactive impedances can be shown graphically as two arrows that are perpendicular to another **(Figure 3)**. If this is to be displayed in a more exact manner mathematically, these two vectors should be inserted into a system of coordinates where the real impedances are inserted

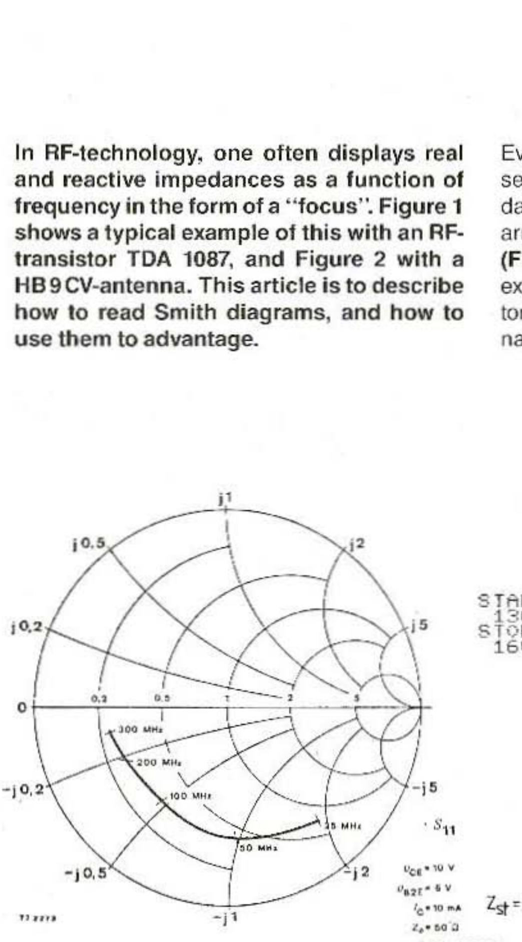

Fig. 1: Input impedance of a TDA 1087 as locus in a Smith diagram

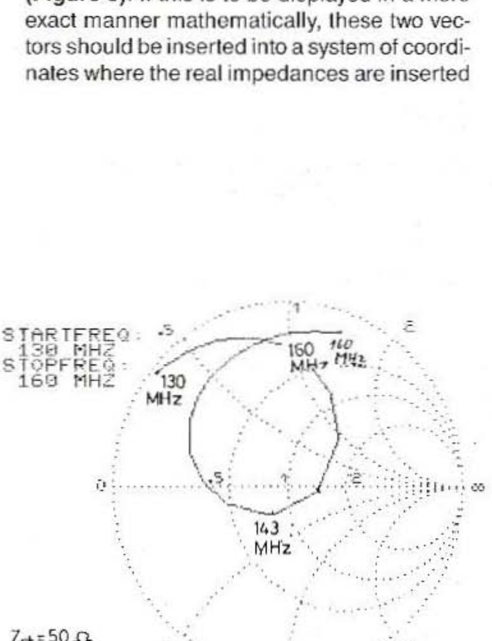

Fig. 2: Impedance locus of a HB9CV antenna for the 2 m band

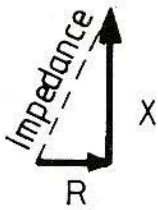

Fig. 3: Real and reactive impedance

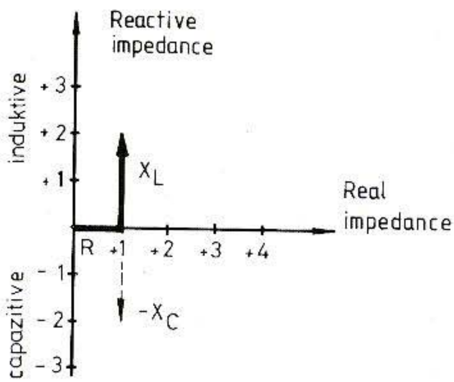

Fig. 4: Real and reactive impedances in a coordinate system

to the right, and the reactive impedances vertically. A vector pointing upwards (positive sign) represents an "inductive reactive impedance", and a vector pointing downwards (negative sign) shows a "capacitive reactive impedance" **(Figure 4).**

This impedance plane has the disadvantage that it must be extended infinitely if it is to display all possible impedance conditions, such as the infinite impedance present under non-load conditions.

This problem can be solved by "bending" the vertical coordinates in the impedance plane **(Figure 5, left)** to form circles. Of course, the vertical axis must form the outer circle **(Figure 5, center);** the reactive impedance values + ∞ and − ∞ are in the "finite" then.

This is where the outer circle **(Figure 5, right)** intersects the horizontal axis. The consequence of this is that the real-impedance axis is no longer linearly scaled. Here, also the impedance value ∞ comes into finite values and meets the other two infinite points at the right.

The bending process also has an effect on the horizontal coordinates which are in the form of sectors. With increasing inductive or capaci-

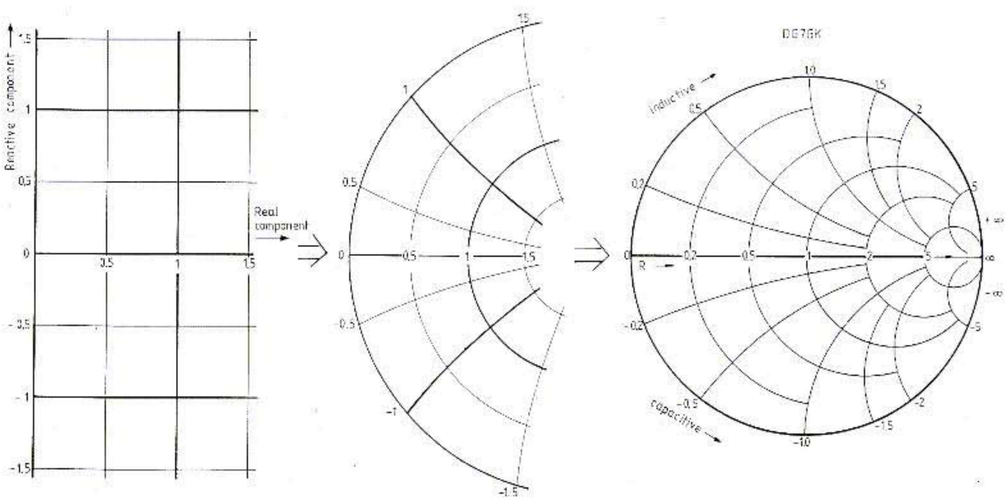

Fig. 5: Transition from rectangular coordinate system to Smith diagram

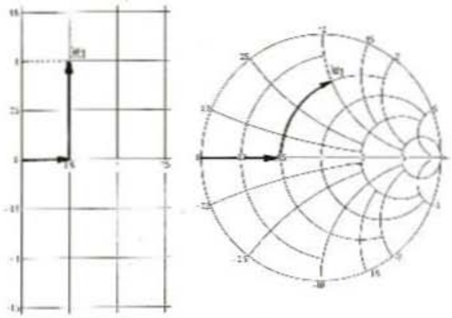

Fig. 6a:
Series connection of real and reactive component: Real component = 0.5; reactive component = 1.0. "+" means "inductive".

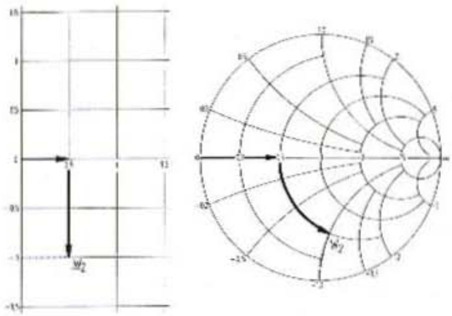

Fig. 6b:
Series connection:
Real component = 0.5;
reactive component = −1.
"−" means "capacitive".

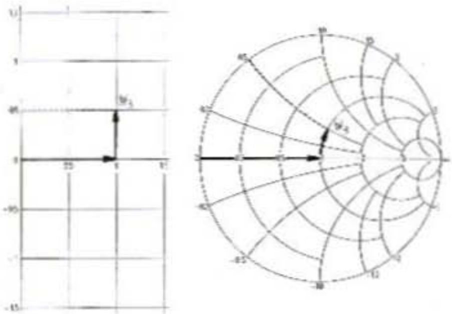

Fig. 6c:
Series connection:
Real component = 1.0;
reactive component = +0.5

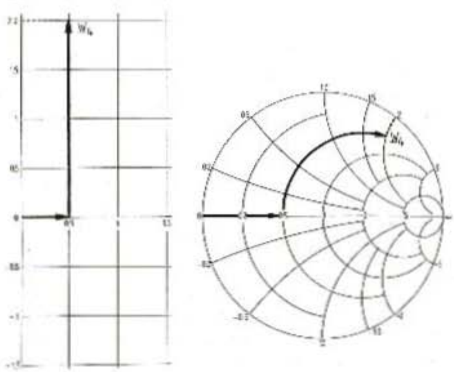

Fig. 6d:
Series connection:
Real component = 0.5;
reactive component = +2

tive reactive impedance they become continuously shorter and are shifted more and more to the infinite point. The whole rectangular system of coordinates in the impedance plane with its straight coordinates is thus transposed to a curved coordinate system that fills the inside of a circle. Only the right angles (intersections of originally horizontal and vertical coordinates) remain intact during the "bending" process.

It is advisable to practise by inserting the real and reactive impedances in the left half of the Smith diagram, before attempting to enter into the area where the originally vertical coordinates transpose into the horizontal and finally reverse the direction, or where the originally horizontal coordinates reverse their direction. Several points are given in **Figure 6**a to d (**W**$_1$, **W**$_2$, **W**$_3$ and **W**$_4$). The associated reactive and real impedance components must be taken from the bent coordinates. **W**$_4$ has an extremely high reactive component, which means that this point has exceeded the vertex of the circle. The insertion and extraction of data in this area is very complicated. In this range in the vicinity of infinite values, the coordinates are very close together, which means that only a few can still be inserted. Intermediate values must be read off or inserted by interpolation.

On studying Figure 6a to d as well as 1 and 2, one could assume that only impedances in the order of 0.1 Ω to approximately 2 Ω are suitable for the diagram. This is, however, not the case in practice, since only standard values are inserted into the diagram. This **standardization** allows the same diagram to be used universally.

The standardization process is now to be shown with the aid of an **example:** A series circuit exhibiting a real impedance of 20 Ω and a reactive impedance of 40 Ω is to be inserted into the diagram. If standardization were not used, it would be necessary to insert the value 20 or 40 virtually at ∞, which would be useless due to the inaccuracies. Standardization on the other hand means that it is necessary to **divide** the given impedance values by a suitable, so-called standardizing impedance Z_{st}.

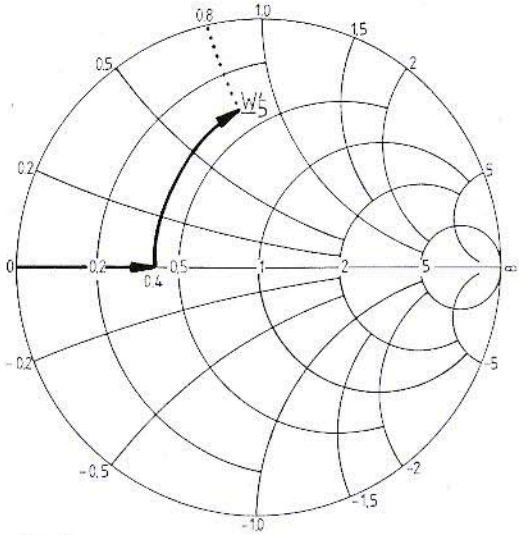

Fig. 7:
Real impedance = 20 Ω;
reactive impedance = 40 Ω
Standardized: Real component = 0.4
Reactive component = 0.8 } **= W'$_5$**

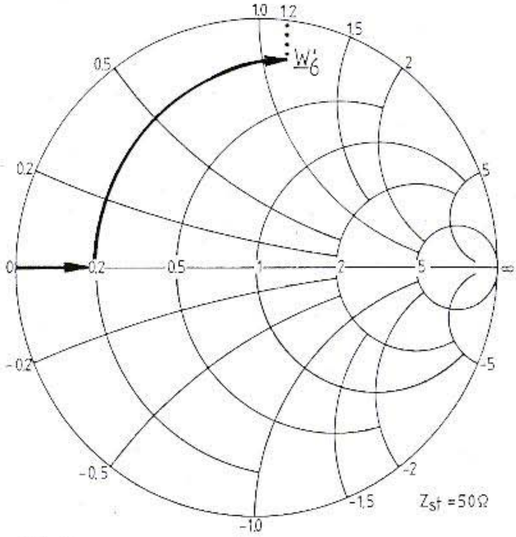

Fig. 8:

W$_6$ is standardized:	**Real component = 0.2** **Reactive component = 1.2**
After destandardization	**Real component = 10 Ω** **Reactive component = 60 Ω**

In our case, we select a Z_{st} of 50 Ω. This results in a standardized real component of 20 Ω/50 Ω = 0.4; and a standardized reactive component of 40 Ω/50 Ω = 0.8.

The standardized values 0.4 and 0.8 are inserted into the diagram **(Figure 7)**, and it can be seen that the resulting point $\underline{W}'_5$ is located very favourably. In our example, 0.4 and 0.8 are numerical values representing the type of an impedance, with 1 as unit.

If one reads such numerical values out of the diagram, one must know the value of the standardizing impedance applied before the entry into the diagram. Another **example: In Figure 8** one will see a point $\underline{W}'_6$ which is to be found on the real-impedance coordinate 0.2, and on the reactive-impedance coordinate 1.2. Since the standardizing impedance Z_{st} = 50 Ω is marked on the diagram, one knows that these values are based on a standardized impedance of 50 Ω. If one wishes to know the actual impedance values, it is necessary to "de-standardize" them.

This is carried out by **multiplying** them with the standardizing-impedance values: The resulting real-impedance value is

$Z = 0.2 \times 50\,\Omega = 10\,\Omega$,

and the actual reactive-impedance is

$X = 1.2 \times 50\,\Omega = 60\,\Omega$.

The values also receive their actual unit "Ω".

In principle, the selection of the standardizing-impedance value can be made freely, however, in practice one is dealing with real and reactive impedances that are to be matched to a certain impedance, such as a source or load impedance. Another application would be to match the characteristic impedance of a transmit antenna to a certain impedance of the feeder cable. If one wishes to use the advantages of the diagram – that is, reading out the value of the return loss of the load or antenna impedance from the diagram, as a function of the source or load impedance – it will be necessary to standardize the diagram to the impedance of the source, that is the source impedance or the impedance of the line. Since an impedance of 50 Ω is usually used in commu-

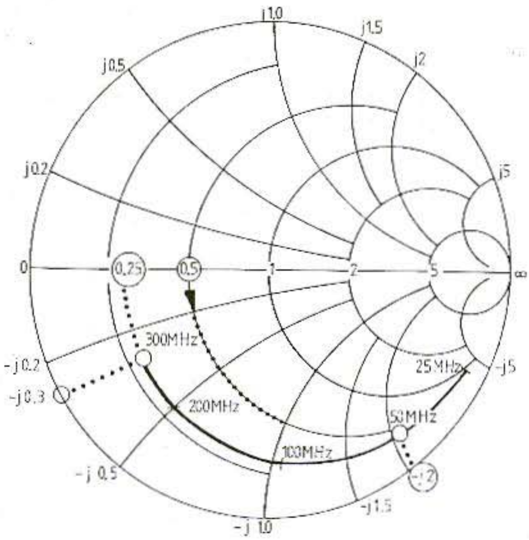

Fig. 9: Determining the input impedance of a transistor with respect to real and reactive component at 50 and 300 MHz

nication technology, it is favorable to select this impedance as standardizing impedance. In Figure 1, an impedance Z_o = 50 Ω was given by the manufacturer. This Z_o is the standardizing impedance which we have designated Z_{st} in this article. Fundamentally speaking, it is always necessary to give the value of the standardizing impedance used when displaying impedances in a Smith diagram!

Finally, a further example is to demonstrate once again the reading of Smith diagrams and the de-standardization process in conjunction with the RF-transistor TDA 1087 (Figure 1). This diagram is repeated in **Figure 9**. The **question** is: What is the impedance (real and reactive components) of the transistor at 50 MHz and 300 MHz?

Solution: The 50 MHz-point is to be found on the locus at a real component of "0.5", and a reactive component of approximately "–2" (the factor "j" only shows that it is a reactive and not a real component). The minus-sign means that it is a capacitive reactive component.

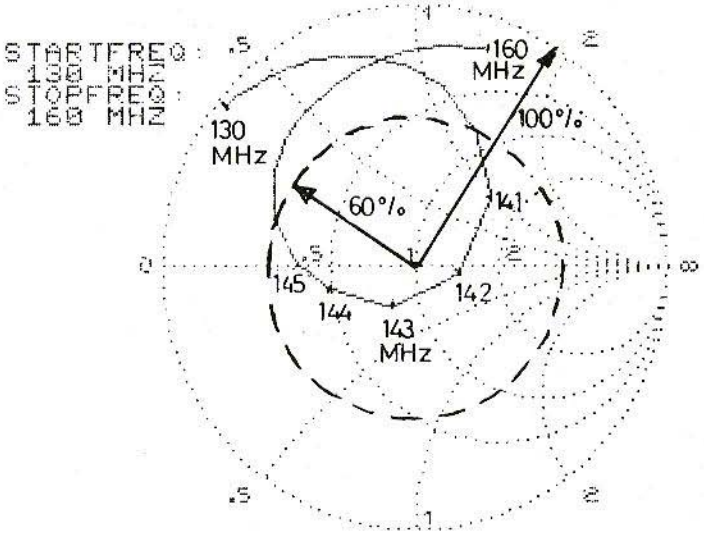

Fig. 10: Locus of an antenna impedance: Return loss circle |r| = 60%

After de-standardizing, the following results at 50 MHz: Real impedance R = 0.5 x 50 Ω = 25 Ω; reactive impedance X_c = −2 x 50 Ω = −100 Ω ("−" means "capacitive"). The 300 MHz-point is to be found on the locus at a real component of "0.25" (estimated) and a reactive component of approx. "−0.3".

After de-standardization, this results at 300 MHz in the following:

Real impedance R = 0.25 x 50 Ω = 12.5 Ω;
reactive imp. X_c = −0.3 x 50 Ω = −15 Ω.

The advantage of the return loss diagram is to be shown together with a HB9CV-antenna. The locus of the impedance of this antenna (Figure 2) is repeated in **Figure 10.** The diagram is standardized to 50 Ω and the antenna is to be connected to a feeder cable of also 50 Ω, which means that it is not necessary to re-standardize the locus. It is now possible to simply determine in which range the antenna does not exceed a certain return loss! However, this requires one more curve in addition to the many other curves already existing in the diagram.

The return-loss limits are indicated by the radial length of a circle whose center is the **geometric** center of the diagram. The radius of the outer circle is used as a reference value, since all impedance values on the outer circle possess a return loss of 100% with respect to the standardizing impedance. If one wishes to mark the range in which the locus contains impedances having a certain return loss with respect to the standardizing impedance of 50 Ω, for instance a return loss for 60%, it is only necessary to form a circle around point 1 (center of the diagram) which has a radius of 60% that of the outer circle.

All impedances that are to be found within this circle will have a return loss of less than 60% with respect to the standardizing impedance, and thus with respect to the impedance of the feeder cable. It will be seen that the antenna is matched to the cable with a return loss of less than 60% in a frequency range of 141 MHz to 145 MHz. If the **voltage standing wave ratio VSWR** is to be read off, this is possible by reading it out of the diagram between 1 and ∞ at the intersection between the appropriate return loss curve and the horizontal axis.

It will be seen that one is able to solve many problems encountered with return loss, standing wave ratio, and matching, without having to carry out complex calculations.