



Optimization of Model Parameters of Experimentally Studied Broadband Transmission Line Transformers with Ferrite Toroidal Cores Amidon FT82-43 and FT114-43

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Abstract: This paper presents the optimization of amplitude-frequency responses and qualitative parameters of broadband transmission line transformer models based on the obtained experimental and simulation results. There are presented comparative assessments between amplitude-frequency responses of broadband transmission line transformers with ferrite toroidal cores Amidon FT82-43 and FT114-43 and coefficient of resistance ratio 1:1. Optimized values of model parameters are given in tabular form as well as the type of obtained graphical dependencies.

Keywords: broadband transmission line transformers; studies; qualitative parameters; optimization.

I. Introduction

Broadband co-ordination and transformation of input and output resistance of a high-frequency amplifier, between two adjacent amplifier stages as well as broadband power aggregation and division can be carried out by transmission line transformers employing an electromagnetic connection between the primary and secondary windings. To provide the necessary transformation coefficient of resistances and minimum deco-ordination is an important prerequisite for achieving a wide operating frequency band. These transformers have high efficiency and reliability and through them can be made: galvanic dissociation between nodes and units of the equipment, transition from asymmetric to symmetric I/O and vice versa; they have small sizes, etc.

Broadband Transmission Line Transformers (BTLT) are constructed employing appropriately interconnected transmission lines (most frequently it is a twisted pair of copper enamelled wires), positioned on a ferromagnetic core which is mostly of toroidal shape [1], [7]. The input signal excites electromagnetic waves whose linear combinations depending on the type of line connection, determine the output signal voltage. Since the resistance transformation of BTLT is associated with changes in the coefficient of voltage transmission $A_u = n \cdot z$ [7] when $nz=4:1$, $nu=2:1$ and $A_u=0.5$. For $nz=1:4$, $nu=1:2$ and $A_u=2$.

II. Simulation Results of Complete Models of BTLT with Amidon FT82-43 and FT114-43 with $nz=1:1$

The complete models of BTLT as a result of the modeling of toroidal ferrite cores (FT) manufactured by Amidon and BTLT with ferrite core FT82-43 and $nz=1:1$ [4], [3] are shown in Fig. 1: Fig. 1a – with ideal transformer (T1) and Fig. 1b with a voltage-controlled voltage source (V). By setting its transmission coefficient a , a corresponding value of A_u is modeled when $nz \neq 1:1$.

**Figure 1: Complete models of broadband transmission line transformers
with ferrite toroidal core Amidon FT82-43 and $nz=1:1$.**

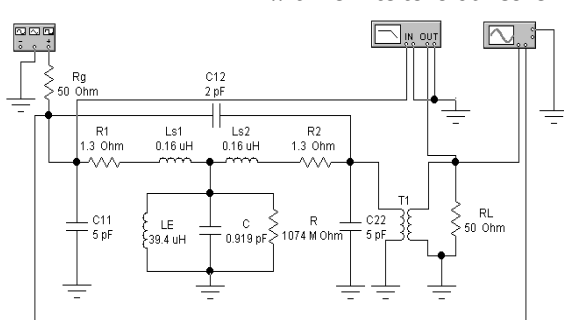


**Fig. 1a. Model1 of BTLT with
ideal transformer**

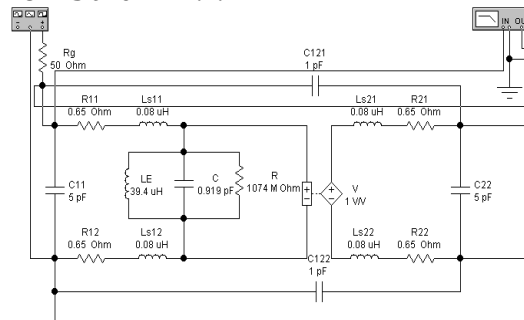


**Fig. 1b. Model2 of BTLT with
voltage-controlled voltage source**

The obtained frequency bandwidth Δf at a level of 3 dB, determined by amplitude-frequency responses (AFR) of the two models as a result of simulation, are respectively $\Delta f = f_h - f_b = 51,7 \cdot 10^6 - 130,4 \cdot 10^3 \approx 51,57$ MHz (for Model1) and $\Delta f = 56,8 \cdot 10^6 - 206,3 \cdot 10^3 \approx 56,6$ MHz (for Model2) where f_h is upper and f_b is low cut-off frequency.

From the performed Parameter Sweep analyzes to establish the influence of the values of the model parameters of Model1 and Model2 on the received amplitude-frequency responses and parameters it has been found:

- the value of the active resistance of the toroidal ferrite core R does not affect the obtained amplitude-frequency response – width and amplitude of the signal;
- increasing the value of the equivalent inductance L_E , including the inductance of the ferrite core L and the natural inductances of the primary and secondary side L_{11} and L_{22} ($L_E = L_{11} + L_{22} + L_1$), which can be accomplished by increasing the number of turns and/or by increasing the magnetic permeability of ferrite core μ_r , extends the low frequency range. The efficiency at low frequencies can increase the range up to 25 times ($f_b(L_E=39,4\mu H)=103,4$ kHz, $f_b(L_E=1000\mu H)=4$ kHz);
- reducing the value of leakage inductance L_{s1} (or L_{s2}) greatly enhances the efficiency of the BTLT model at high frequencies ($f_h(L_{s1}=0,016\mu H)=52,2$ MHz, $f_h(L_{s1}=0,5\mu H)=24,4$ MHz);
- smaller values of distributed inter-winding capacitance between transmission lines C_{12} in the range $(0,1 \div 10)$ pF expand the high frequency range by increasing the value of the upper cut-off frequency of the BTLT Model1 f_h ($f_h(C_{12}=2pF)=51,6$ MHz, $f_h(C_{12}=10pF)=41,8$ MHz) of the order of ± 20 %. In practice this can be achieved with less or no twisting between the used transmission lines and uniform distribution of turns along the length of the used toroidal ferrite core;
- the value of the distributed shunt capacitance of the primary or secondary winding, respectively C_{11} or C_{22} , does not affect the width of the band Δf .

Therefore, the low frequency range of the BTLT model can be adjusted by the value of the magnetic permeability of the used ferrite toroidal core μ_r and/or by changing the number of turns, and the upper cut-off frequency is inversely proportional to the values of distributed inductance L_s and inter-winding capacitance C_{12} . After completing the comparative assessment between the AFR of the two BTLT models - Model1 (Fig. 1a) and Model2 (Fig. 1b), their similarity and change in the values of f_b , f_h and Δf within narrow ranges is established. Model2 provides a little wider bandwidth in comparison with that of Model1 that is translated to the area of higher frequencies. This is determined by the obtained greater value of f_h . A difference is obtained in Model2 by increasing the value of model parameter L_{s11} where in the area of high frequencies in the frequency range of $(400 \div 600)$ MHz resonances arise.

The simulation results obtained from the study of both models of BTLT - Model1 and Model2 with ferrite toroidal core Amidon FT114-43 are similar.

Fig. 2 shows the comparative assessment between the obtained AFR of BTLT with ferrite toroidal cores FT82-43 and FT114-43 respectively for Model1 and Model2, and Table I presents the values of f_b , f_h and Δf .

Table I The f_h , f_b and Δf values of Model1 and Model2.

Model of	Model	f_h , MHz	f_b , kHz	Δf , MHz
BTLT with FT82-43	Model1	51,70	130,40	51,57
	Model2	56,80	206,30	56,60
BTLT with FT114-43	Model1	49,10	94,04	49,00
	Model2	52,97	188,50	52,78

Figure 2 Comparative assessment between the obtained AFR of BTLT.

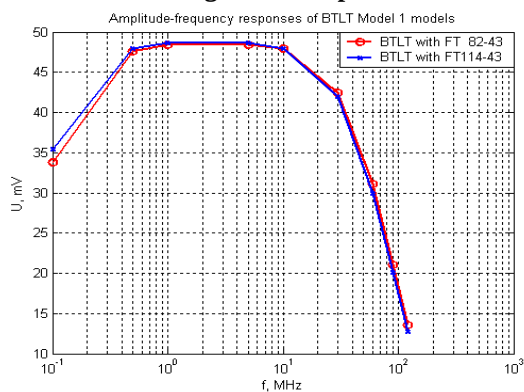


Fig. 2a. AFR of Model1 of BTLT with ferrite toroidal cores FT82-43 and FT114-43

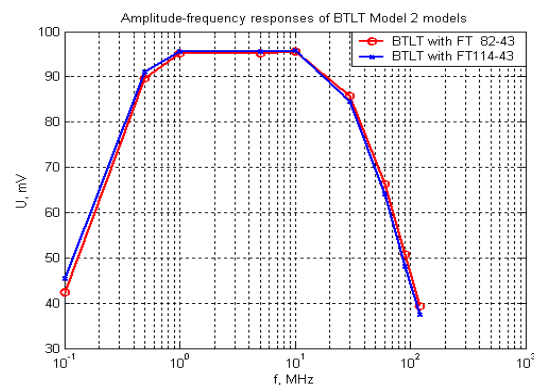


Fig. 2b. AFR of Model2 of BTLT with ferrite toroidal cores FT82-43 and FT114-43

The main difference between the AFR of BTLT models with ferrite toroidal cores Amidon FT82-43 and FT114-43 Model1 and Model2 is in the value of the coefficient of voltage transmission A_u . In Model2, containing a

voltage-controlled voltage source, $A_u \approx 0,96$, and in Model1 it is twice smaller. A minimum difference in the slopes of drop of AFR at low and high frequencies has been found which for Model2 are steeper.

From Fig. 2 it has been found that there is no significant difference between AFR of Model1 and Model2 of BTLT with different dimensions of the used ferrite toroidal cores, therefore, it can be inferred, that the dimensions of the used toroidal ferrite cores have no significant effect on the obtained characteristics and implemented qualitative parameters. There is a slight difference in the drop of AFR at low frequencies which is of the order of 0,5-1 % and for the purposes of modelling and simulation studies it can be ignored. It is due to the difference in the value of the model parameter equivalent inductivity L_E , determined mainly by the inductance of the ferrite core in the presence of a coil of BTLT, where the larger dimensions and hence the value of the cross-sectional area of ferrite core A_e , in cm^2 increase the value of L_1 .

From comparative assessment of the obtained simulation results of the modeled BTLT with ferrite toroidal cores Amidon FT82-43 and FT114-43 it can be concluded that Model2 represents more accurately the essence of the real high-frequency transmission line transformers because it has A_u approximately 1 required for modeling of $nz=1:1$, provides a larger AFR in comparison with that of Model1, possesses steeper slopes of drop at low and high frequencies. By setting the value of the transmission coefficient of the voltage-controlled voltage source V , the voltage transmission coefficient can be modeled in transforming BTLT ($nz \neq 1:1$). In such cases when $nz=4:1$, $A_u=2:1$ and $A_u=0,5$, and when $nz=1:4$, $A_u=1:2$ and $A_u=2$.

Experimental studies of BTLT with ferrite toroidal cores Amidon FT82-43 and FT114-43 with 7 windings of the twisted pair of copper enamelled wires with a diameter $d=0,62$ mm when the number of twists is equal to 3 and 5 per 1 cm are shown in [3].

III. Comparative Assessment between Experimental and Simulation Results

Fig. 3a and Fig. 3b present the comparative assessment of the AFR obtained by simulation studies of Model1 and Model2 and those from experimental studies of the implemented BTLT with 3 and 5 twists per 1 cm when $nz=1:1$ for ferrite toroidal cores Amidon FT82-43 and FT114-43, respectively.

In Table II are summarized the values of the qualitative parameters of BTLT with ferrite toroidal cores Amidon FT82-43 and FT114-43 (Model1 and Model2, 3 and 5 twists per 1 cm) obtained from the AFR implemented by experiment and simulation.

Figure 3 Comparative assessment between AFR obtained by experiment and simulation.

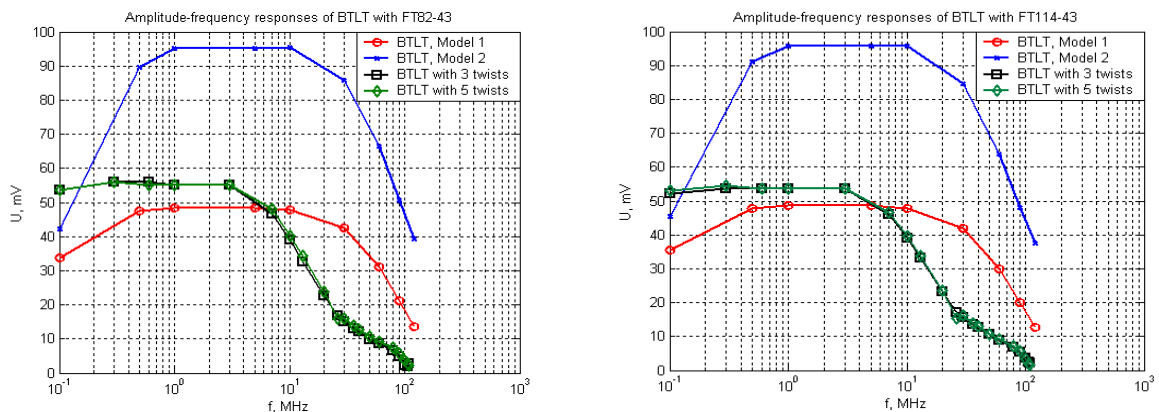


Fig. 3a. BTLT with ferrite core Amidon FT82-43

Fig. 3b. BTLT with ferrite core Amidon FT114-43

Table II Qualitative parameters of BTLT with ferrite cores Amidon FT82-43 and FT114-43 when $nz=1:1$ (Model1 and Model2, BTLT with 3 and 5 twists per 1 cm), obtained from AFR implemented by experiment and simulation.

Mod/Number twists per 1 cm	U_i , mV	BTLT with ferrite core FT82-43			BTLT with ferrite core FT114-43		
		f_b , kHz	f_h , MHz	Δf , MHz	f_b , kHz	f_h , MHz	Δf , MHz
Model1	100	130,40	51,70	51,57	94,04	49,00	48,90
Model2	100	206,30	56,80	56,60	188,50	52,97	52,78
3 twists	136	100,00	10,00	9,90	100,00	9,90	9,80
5 twists	136	10,00	9,90	9,89	11,00	10,90	10,00

From the comparative assessment between AFR obtained by simulation and experimental studies and presented in Fig. 3a and Fig. 3b in graphical form it has been established that:

- the difference between the graphical dependences and the quality parameters (Table II) of practically implemented BTLT with 3 and 5 twists of transmission lines per 1 cm is minimum;
- the obtained AFR of Model1 approximates more to the experimentally obtained one in shape and qualitative parameters;
- the experimentally obtained AFR are narrower (Δf is of the order of 10 MHz) and are shifted in the area of lower frequencies;
- the AFR obtained by simulation cover the operating frequency range of the used toroidal ferrite cores set by the manufacturer more precisely.

Based on the obtained and presented experimental AFR and qualitative parameters of implemented BTLT with ferrite toroidal cores Amidon FT82-43 and FT114-43 using multiple simulation studies, optimization of the values of the model parameters of Model2 has been performed as the results obtained by simulation have been approximated to the experimental ones to the highest degree. The equivalent circuit of Model2 and the realized from it: transmission coefficient A_u , slopes and parameters of AFR are much closer to the physical representation and functional characteristics of BTLT in comparison with those of Model1.

In Table III are presented calculated and optimized values of model parameters of Model2 of BTLT with ferrite toroidal cores Amidon FT82-43 and FT114-43 according to the carried out experimental studies and obtained results.

Table III Calculated and optimized values of Model2 model parameters of BTLT with ferrite cores Amidon FT82-43 and FT114-43.

BTLT ($nz=1:1$)	Parameter	Calculated model parameters	Optimized values of model parameters
BTLT with FT82-43	L_E , mH	39,40	500,00
	L_S , μ H	0,08	0,37
	C_{12} , pF	1,00	1,00
	a , V/V	1,00	0,55
BTLT with FT114-43	L_E , mH	42,63	500,00
	L_S , μ H	0,085	0,37
	C_{12} , pF	1,00	1,00
	a , V/V	1,00	0,55

Table IV presents the values of the qualitative parameters obtained from experimental and simulation studies for calculated and optimized values of model parameters of Model2 of BTLT with ferrite toroidal cores Amidon FT82-43 and FT114-43.

Table IV Implemented parameters of Model2 of BTLT with ferrite cores Amidon FT82-43 and FT114-43 with experimentally obtained results and those of simulation studies for calculated and optimized values.

BTLT	Parameter	Experimental values when there are 3 twists per 1 cm and $U_i = 136$ mV	Parameters from simulation studies	Optimized simulation parameters	ε between experimental and optimized parameters, %
FT82-43	A_u	$\approx 1,0$	$\approx 0,96$	$\approx 0,96$	$\approx 1,0$
	f_b , kHz	100,0	206,30	106,25	6,3
	f_h , MHz	10,0	56,80	11,53	15,3
	Δf , MHz	9,9	56,60	11,51	16,3
FT114-43	A_u	$\approx 1,0$	$\approx 0,96$	$\approx 0,96$	$\approx 1,0$
	f_b , kHz	100,0	188,50	106,10	6,1
	f_h , MHz	9,9	52,97	10,70	8,0
	Δf , MHz	9,8	52,78	10,68	9,0

As a result of the optimization of the AFR implemented by simulation from the experimental results obtained (Table IV), it has been established that the greatest difference between optimized and calculated values of model parameters of Model 2 of BTLT with ferrite toroidal cores Amidon FT82-43 and FT114-43 exists in the value of equivalent inductivity L_E . From the conducted parameter sweep simulation studies of the impact of the value of L_E on the slope of AFR at low frequencies it has been found that the slope can be set (optimized) with a great accuracy. In this case, the value of the low cut-off frequency f_b of optimized AFR of Model2 has a relative difference from the actual experimentally obtained one of the order of 6 %.

In Fig. 4a and Fig. 4b are presented the optimized AFR of Model2 obtained by simulation and the experimentally obtained AFR of BTLT with ferrite toroidal cores Amidon FT82-43 and FT114-43, respectively.

Figure 4 Optimized AFR of Model 2 obtained by simulation and experimentally obtained AFR.

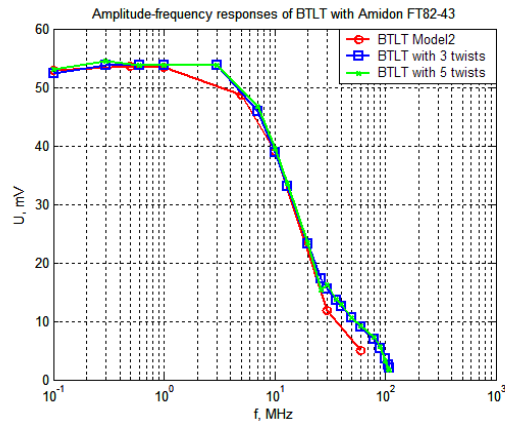


Fig. 4a. BTLT with ferrite core Amidon FT82-43

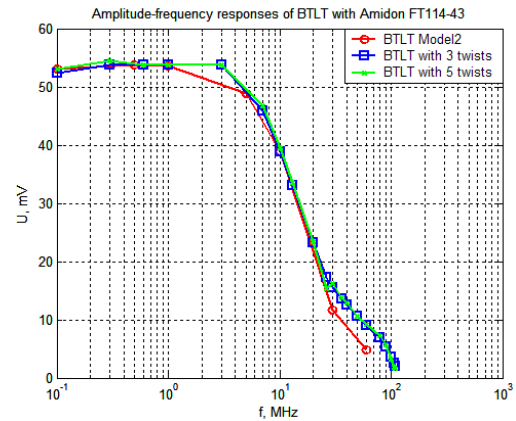


Fig. 4b. BTLT with ferrite core Amidon FT114-43

IV. Conclusion

From the analysis of the presented comparative assessment between experimental and simulation results of obtained AFR of BTLT, it has been established that:

- the width of the transmitted frequency band in the experimentally obtained results is significantly larger than in the simulation ones;
- the linear section of experimentally obtained AFR is significantly larger in comparison with the simulation ones;
- the steepness of drop of AFR at high frequencies is greater during the carried out experimental studies;
- the transmission coefficients of practically implemented BTLT have a little larger values compared to those obtained in the simulation study of their model.

Based on the performed optimization, coefficients can be determined which can be used to adjust dependencies, by which the model parameters of BTLT with specific ferrite cores are calculated with regard to the general case.

A convenience of BTLT model with voltage-controlled voltage source is the fact that the optimization of one model parameter L_E , L_{S1} (L_{S2}) or C_{12} changes the cut-off frequency only in the corresponding frequency range of AFR and its drop remains the same.

Unlike practically implemented BTLT, which show the effect of their bandwidth only in the exact coordination between input and output impedances, the presented models keep the widths of their frequency bands also with arbitrary values.

V. References

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