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VARIABLE SLUG-CONTROLLED COAXIAL TRANSFORMER

Filed July 1, 1969

2 Sheets-Sheet 1

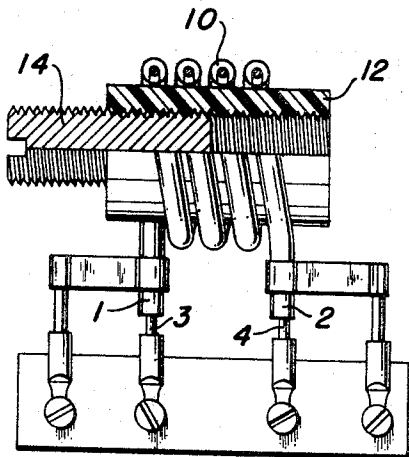


FIG. 1

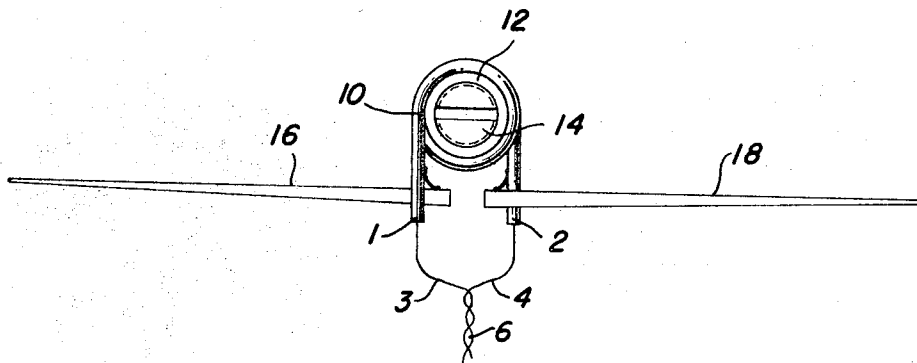


FIG. 2

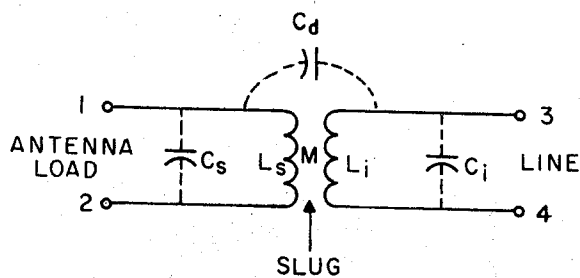


FIG. 3

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REACTANCE X_s , X_i AND X_m MEASURED AT THREE FREQUENCIES USING 1 1/2 TURN 50-OHM COAXIAL CABLE WITH AND WITHOUT SLUGS OF BRASS AND FERRITE

FREQ (Mc/s.)	SHIELD REACTANCE (X_s)			INNER CONDUCTOR (X_i)			MUTUAL REACTANCE (X_m)		
	NO SLUG	BRASS	FERRITE	NO SLUG	BRASS	FERRITE	NO SLUG	BRASS	FERRITE
14	21.3	17.5	34.6	24.2	22.9	38.6	20.57	16.27	36.42
21	32.0	27.4	58.6	40.2	35.6	59.5	35.67	28.20	64.70
28	44.6	37.1	85.7	56.9	49.1	77.7	54.05	42.55	116.87

FIG. 4

FREQ (Mc/s)	$k' = \frac{X_m}{\sqrt{X_s X_i}}$			$R_d = \frac{X_m^2}{50}$ OHMS		
	NO SLUG	BRASS	FERRITE	NO SLUG	BRASS	FERRITE
14	0.906	0.813	0.997	8.462	5.294	26.528
21	0.994	0.903	1.096	25.447	15.905	83.722
28	1.073	0.997	1.432	58.428	36.210	273.172

FIG. 5

FREQ (Mc/s)	SLUG TURNS	$R_d = X_m^2 / 50$	
		OUT	IN
14	3.5	128.0	56.7
	2.5	27.1	18.4
	1.5	8.4	5.3
21	3.5	1186	305.4
	2.5	721	60.2
	1.5	25	15.9
28	3.5	(*)	(*)
	2.5	193.1	100.7
	1.5	57.9	36.2

FIG. 6

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VARIABLE SLUG-CONTROLLED COAXIAL TRANSFORMER

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ABSTRACT OF THE DISCLOSURE

A coaxial cable coiled, the inner and outer conductors being connected as the primary and secondary windings of a transformer and a metal slug is adjustable along the axis of the coil to change the impedance transformation. The device is excellent for matching the impedance of a resonant load such as an antenna to a feed line of any characteristic impedance.

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

Many techniques are available for transforming or matching impedance of coupled balanced or unbalanced circuits. Commonly used lumped-constant devices include two terminal-pair low-loss LC networks in a form of one or more sections of L, T or pi configuration. Distributed parameters often enter into the design and operation of these lumped-constant networks and play a major role in many techniques utilizing forms of transmission lines such as quarter wave transforming sections, exponential lines, compensated lines, and line sections in various series and parallel combinations. However, none of these techniques give the convenient adjustment and the simplicity of design afforded by the following described compact transforming structure.

SUMMARY OF THE INVENTION

A coaxial cable including a tubular outer conductor enclosing an inner conductor is wound with one or more turns on an insulating tubular form, the two ends of each of the inner and outer conductors being connected, respectively, to the circuits the impedances are to be matched. A metal slug of either magnetic or non-magnetic material is adjustable along the axis of the coil and is found to vary the self and mutual reactances of the windings of the transformer. The load side of the transformer is turned to show zero or minimum reactance and then the slug is adjusted to match the impedance of the load to the feed line. Because of interdependence of the self and mutual reactances some tuning may be required after each slug adjustment.

Other objects and features of this invention will become apparent to those skilled in the art by referring to the preferred embodiment described in the following specification and shown in the accompanying drawings in which:

FIG. 1 is a plan view partly in section of one specific coaxial transformer of this invention;

FIG. 2 shows the coaxial transformer coupling a feed line to a dipole antenna;

FIG. 3 is a diagram of the equivalent circuit of the transformer of this invention;

FIGS. 4, 5 and 6 are, respectively, tables of empirical data taken from the transformer of this invention.

The transformer embodying this invention and shown in FIG. 1 comprises a length of coaxial cable 10 wound on a cylindrical tube 12 of low loss dielectric material. The turns may be one or more in number and the pitch of the turns may be fixed with dielectric spacing material, or the turns may be laid one against the next. The metal member 14, usually called a slug, is of metal and, surprisingly, may be of either magnetic or non-magnetic material. The slug is adjustable lengthwise within the coil of coaxial cable, the preferred method of adjustment being screw threads on the slug and in the insulating cylinder 12. The two ends 1 and 2 of the shield or outer conductor are trimmed back to expose the two ends 3 and 4 of the inner conductor. Each conductor end is suitably capped and connected to screwdriver terminals on a terminal block for convenience of circuit wiring and switching.

One useful application of the transformer of FIG. 1 is shown in FIG. 2 where terminals 1 and 2 of the shield are connected directly to the two halves 16 and 18 of a dipole antenna and the inner conductor terminals 3 and 4 are extended to the feed line 6 of any length and of any impedance characteristic. As will be seen the slug 14 can be adjusted to match the impedance of the antenna load to the impedance of line 6.

FIG. 3 shows a simple schematic diagram of the variable transformer of FIG. 1. The cable shield or outer conductor forms the inductor L_s and the inner conductor forms inductor L_i . These inductors are intercoupled with mutual inductance M and coupling capacitance C_d , the latter being determined largely the length and electrical characteristics of the coaxial cable and very little by the position of the slug. The effective distributed capacitances C_i and C_s are associated respectively, with the inner and outer conductors. It is to be noted that the distributed capacitances can be represented in various series and parallel configurations for different combinations of terminal connections. Energy dissipation is neglected here.

By different combinations of frequencies and numbers of turns in the coils of coaxial cable commercially known as RG/142B/U, impedance measurements show that the insertion of a brass slug causes L_s , L_i and M to decrease by approximately the same proportion throughout a moderate range of frequencies. The test frequencies were in the 14 to 28 megacycle range. The insertion of a ferrite slug, however, causes the L_s , L_i and M values to increase by about the same proportion depending on the permeability of the ferrite material and the range of frequencies employed. The table of FIG. 4 shows the changes in L_s , L_i and M caused by inserting a ferrite slug of medium to high permeability are greater than the changes caused by inserting a brass slug of comparable length and cross section.

From the observations above concerning the increase and decrease in inductances, it should be noted that the coefficient of coupling k can be defined as follows:

$$k = \frac{M}{\sqrt{L_s L_i}}$$

In terms of the reactances, k can be defined as

$$k = \frac{X_M}{\sqrt{X_s X_i}}$$

The coefficient of coupling is not normally changed appreciably by inserting a magnetic or non-magnetic slug, the coefficient being approximate unity in all cases.

In many antenna matching applications, resonant primary and secondary (load) circuits are often desired. In FIG. 3 a transmission line is coupled to an antenna through the transformer of this invention. From basic coupled theory under these resonant conditions the desired

mutual reactance X_M is related to the effective series primary resistance R_{pri} and secondary resistance R_{sec} by the expression

$$X_M = \sqrt{R_{pri} R_{sec}}$$

where X_{pri} and X_{sec} are resonant and are both equal to zero. This equation may be rearranged to show the value of antenna resistance R_a that matches a 50 ohm feed line

$$R_{sec} = R_a = \frac{X_M^2}{50}$$

where $R_{pri} = 50$ ohms. In antenna applications these resonant conditions can be obtained in the antenna circuit easier by adjusting the antenna's length for $X_{sec} = 0$ or by adding the proper value of reactance in the antenna circuit. Similarly, suitable reactance, such as C_i can be added to obtain resonance in the primary circuit.

The foregoing observations are substantiated by the empirical data in the table of FIG. 4 where all reactance values are expressed in ohms at three different frequencies. With no slug, variations of both X_s and X_i exhibit somewhat increasing slopes as a function of frequency illustrating effects of effective shunt capacities C_s and C_i in FIG. 3.

The measured data in the table of FIG. 4 have been used in computing the apparent coefficients of coupling and antenna input resistance shown in the table of FIG. 5 that can be matched to a 50 ohm source under resonant conditions. The computed coefficients of coupling which are greater than 1 are mentioned here to indicate close coupling between transformer turns and rather prominent effects of stray parameters.

The values of R_a shown in FIG. 5 are obtained from computed values of X_M found in FIG. 4. Referring to FIG. 3, reactive measurements were made at terminals 1 and 4 with the coils connected series aiding where terminals 2 and 3 were connected together. In addition reactance measurements were made at each frequency with the coils connected series opposing where the measurements were taken at terminals 1 and 3 with terminals 2 and 4 connected together. Calling these reactances X_a and X_o , respectively, the apparent mutual reactances were derived from the expression

$$X_M = \frac{X_a - X_o}{4}$$

The range of antenna resistance R_a shown in the right hand columns of Table 3 of FIG. 6 include values of input resistance of a variety of common antenna types that are commonly operated under resonant conditions. A few examples include: a quarter wave thin monopole over good ground, 35 ohms; half-wave dipole in free space, 74 ohms; close spaced Yagi-Uda array, 5-15 ohms; and two-wire folded dipole in free space, 300 ohms. All values of input resistance mentioned above depend upon details of the antenna design including relative thickness, feed-point details, height above ground, ground conductivity, and proximity of surrounding objects all of which may produce wide variations in the actual input resistance.

In a very simple compact form the adjustable coaxial transformer of this invention affords a rather wide range of resistance transformation. The use of a threaded core facilitates precise adjustment. A long dielectric rod or wooden pole can reach and adjust the slug at the top of an antenna mast. While brass cores afford advantages of

machinability, ferrite materials can be used if the ferrite slug is coated with machinable Teflon or other durable plastics. The advantages of simplicity and convenience of the transformer of this invention becomes especially apparent when the adjustable transformer is paired with the well known delta, gamma or T-match techniques described in radio handbooks. Adjustment of the transformer can cause some undesirable detuning of the antenna circuit as well as of the primary circuit. By careful selection of cable length so that minimum turns are utilized, the primary and secondary reactances of the coaxial transformer can be minimized so that, in turn, changes in X_s and X_i from slug adjustments are also minimized.

What is claimed is:

1. In combination:

two high frequency circuits, and a transformer for coupling together said circuits, said circuit having at operating frequencies unequal impedances looking into the ends of the circuits to be coupled;

said transformer comprising a coil of coaxial cable, the ends of the inner conductor of said cable being connected to one of said circuits and the ends of the outer tubular conductor of said cable being connected to the other of said circuits, and

a metal slug disposed on the axis of said coil and being adjustable along said axis.

2. The combination defined in claim 1 further comprising:

reactance elements in each of said high frequency circuits for tuning the circuits to resonance as said slug is positioned for optimum mutual reactance.

3. In the combination defined in claim 1:

one of said high frequency circuits comprising an antenna, and the other circuit comprising a two-conductor feed line.

4. In the combination defined in claim 1 said transformer further comprising:

a tubular form of insulating material upon which is affixed the turns of said coil,

the interior of said form and the exterior of said slug having matched threads for adjustment of the slug along said axis of the coil.

5. A device for matching the impedance at high frequencies of two dissimilar circuits, said device comprising:

a coaxial cable including a tubular outer conductor enclosing and concentric with an inner concentric conductor, the cable being wound into a coil of a predetermined number of turns, the ends of the inner and outer conductors being adapted for connecting, respectively, to said dissimilar circuits, and

a metal slug being adjustable along to axis of said coil for varying the mutual reactance of said transformer.

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