Some Further Notes on the Gamma Match
What MININEC Models Report

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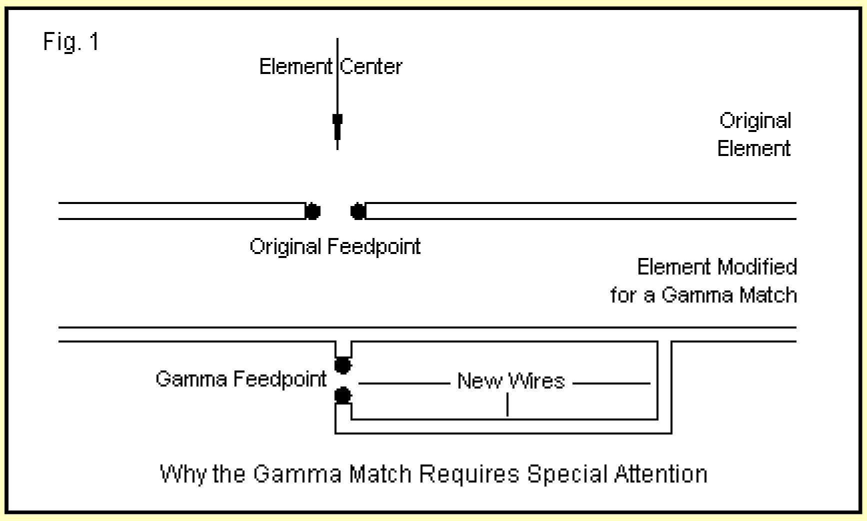
In "Some Preliminary Notes on the Gamma Match," I began (but certainly did not conclude) a comparison between two methods of calculating gamma-match dimensions (specifically, the length of the gamma rod and the required series capacitance) with additional comparisons to a set of MININEC models. Once I translated the two calculation methods (the Healey-Wheeler and the Tolles-Nelson-Leeson systems) into handy spreadsheet formats, they stood ready to deliver any amount of required data on a moment's notice. However, modeling is far less handy in this regard, since each new case requires a new model.

The original investigation revealed some anomalies between the modeling and the calculation methods of finding gamma-match dimensions. For example, both calculation systems show a significant variability in gamma-rod length as we change the ratio of the main element diameter to the gamma-rod diameter. However, the models showed virtually no change for gamma rods ranging from 0.25 up to 1.25 of the main element diameter. Even more interesting was a very preliminary check of gamma rod lengths relative to the initial feedpoint reactance. Calculation methods showed a virtual continuous increase in gamma rod length as the reactance went from a significant capacitive value up to an equally significant inductive value. Models showed a minimum gamma rod length at or near a resonant initial element impedance with increases that vary with reactance, whether capacitive or inductive.

The original survey--driven by a comparison among gamma design methods--had many limitations. Perhaps the primary restriction concerned the very small region of initial antenna impedances used in the examples. The resistive component of the initial antenna element impedance was about 30 Ohms. Gamma matches are capable of matching a wide range of impedances to a given feedline impedance. Hence, further systematic modeling seemed in order. Since even a small survey will involve many models, these notes will focus entirely upon what models have to tell us.

Modeling Issues

One reason for focusing solely upon models in these notes has to do with the basic structure of a gamma match and its representation within an antenna modeling system. **Fig. 1** provides the outline of the gamma match structure in contrast to the element structure without the match in place.



We normally obtain a value for the impedance of a driven element at the element's center, as shown in the upper portion of the sketch. A gamma match adds further wires to the structure and moves the feedpoint, as indicated in the lower half of the sketch. Calculation systems of determining gamma dimensions treat the wire that is parallel to the main element as a transmission line and use equations appropriate to that conception. As a consequence, they do not directly account for the connecting wires at the feedpoint and at the far end of the gamma system. To model a gamma match as a physical structure requires that we include these connecting wires, or else the model will not work. For all models in this study, the end wires will use the same diameter material as the main element.

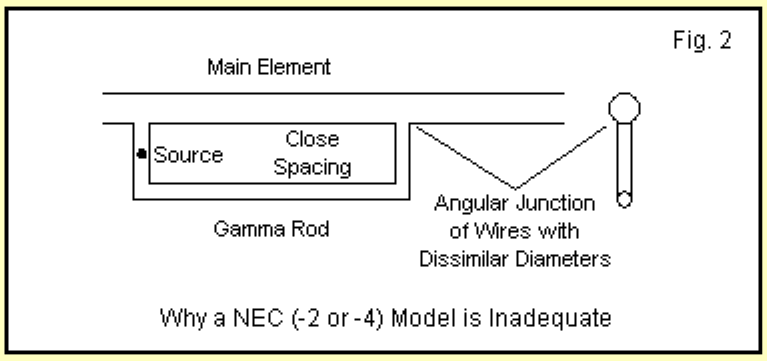
The input data for a gamma match forms a relatively complex set.

- 1. The main element diameter
- 2. The gamma rod diameter
- 3. The center-to-center spacing of the main element to the gamma rod
- 4. The initial feedpoint impedance of the driven element, usually given in series format: R +/- jX Ohms
- 5. The target matched impedance, given solely in resistive terms and usually the characteristic impedance of the main feedline

To simplify our initial work, we shall use a single spacing throughout the exercise. As well, the main element diameter and the gamma rod diameter will be the same. As we review some old data, we shall see some justification in these simplifying maneuvers. Again, to simplify matters, we shall use 50 Ohms as the standard target impedance for the match. This is perhaps the most common value for which we find gamma-match designs.

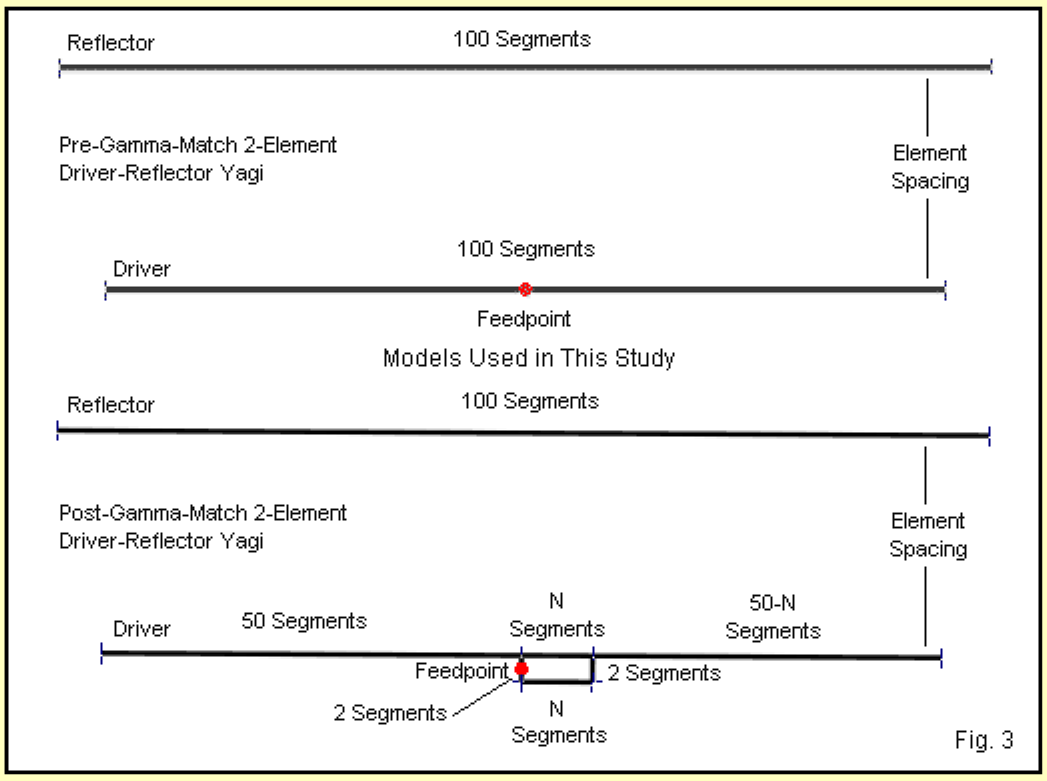
Where the new work will depart significantly from previous work is by beginning with a larger range of initial antenna impedance values. Since we cannot survey everything in one exercise, we shall explore resistive impedance between 15 and 60 Ohms in 15-Ohm increments. We shall also explore reactance values between -j24 and +j24 Ohms in j8-Ohm increments to subdivide the curves more finely.

As in the earlier exercise, we shall use MININEC models. NEC models are simply not up to the task of modeling a gamma match. **Fig. 2** suggests why.



If we were using models with gamma rods that varied in diameter from the main element diameter, NEC would reveal its well known weakness at angular junctions of wires having different diameters. However, the models in this study will use equal diameters for all wires. Nevertheless, with relatively close spacing of wires, NEC also begins to yield errant results, as indicated by average gain test (AGT) scores that depart widely from the ideal value of 1.0000.

Raw MININEC 3.13 (the version available in the public domain) would be equally incapable of accurately modeling gamma matches due to some inherent weaknesses. Unmodified MININEC has difficulties with corner junction, close-spaced wires, and some other aspects of many model geometries. However, Antenna Model has introduced correctives for these problems. In addition, it produces a readily accessible AGT score so that the modeler can evaluate the model undergoing work. Therefore, all models used in this study employ Antenna Model as the operative software.



All models in these notes begin with a "gamma-less" 2-element Yagi having a desired (or usable) driver-element feedpoint impedance, as shown in the upper half of **Fig. 3**. The models will be in the vicinity of 30 MHz. In this frequency region, using 100 segments per element yields segment lengths in the vicinity of 2". This segment length easily accommodates the range of main element and gamma rod diameters that we would normally use in samples--and in regular construction. The gamma-match version of the model makes no change in the reflector element. The driver element retains its initial length, but become 3 model wires. The sketch shows that the number of segments in the gamma-match region is N, so that the total number of segments in this half of the element is 50. However, the value of N will vary according to the required gamma length so that the segments in all 3 parts of the driver have as close to equal lengths as may be feasible. The gamma rod will also have N segments.

The result of these measures produces an internally consistent set of models. However, the data set has not been validated against a set of physical antennas with the modeled properties. Hence, we cannot and do not claim that the exercise reflects the reality of gamma match implementation. That portion of the work is available to anyone with sufficient patience and aluminum stock to build and measure the requisite range of antennas.

Nevertheless, the modeling data provide a mass of information that is ripe for physical testing. As well, they provide a collection of cases against which anyone may compare the results of calculating gamma systems via any of the extant methods.

A Review of Some Previous Results

The original foray into modeling gamma matches used a test frequency of 28 MHz. As well, dimensions appeared in inches. The fundamental model of a 2-element Yagi used 0.12-wavelength spacing between two 0.5" elements. The feedpoint impedance prior to adding a gamma match was 29.84 - j25.73 Ohms for the non-resonant version and 32.07 - j0.05 Ohms for the resonant model. The only difference between the models was the length of the driver element.

The initial test models examined two variables: the spacing between the gamma rod and the main element as well as the size of the gamma rod relative to the main element. I varied the gamma rod diameter between 0.125" and 0.625" in 0.125" increments. I also varied the gamma spacing, using 2", 4", and 6" center-to-center. For each model in the series, I varied the gamma-rod length until I reached a new feedpoint impedance of 50 +/-j0 Ohms, +/-0.1 Ohm in both the resistive and reactive components.

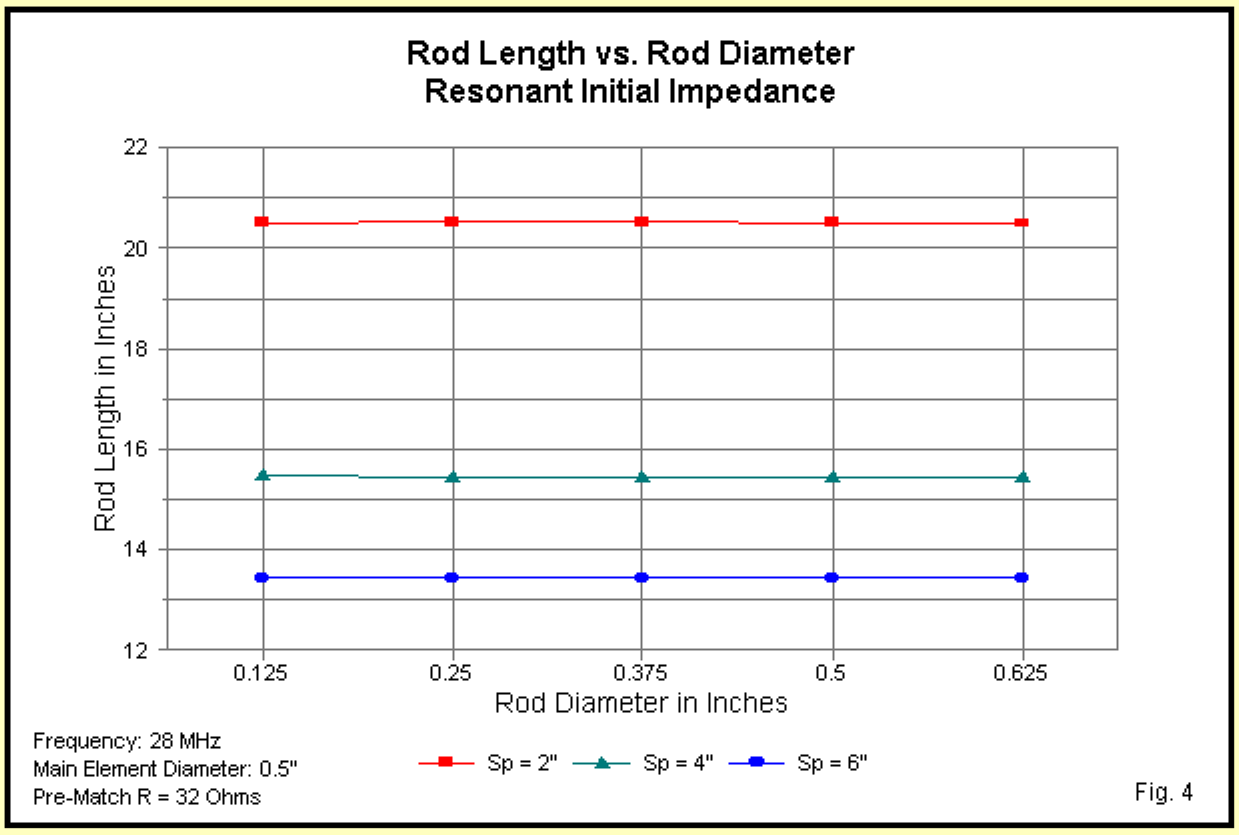
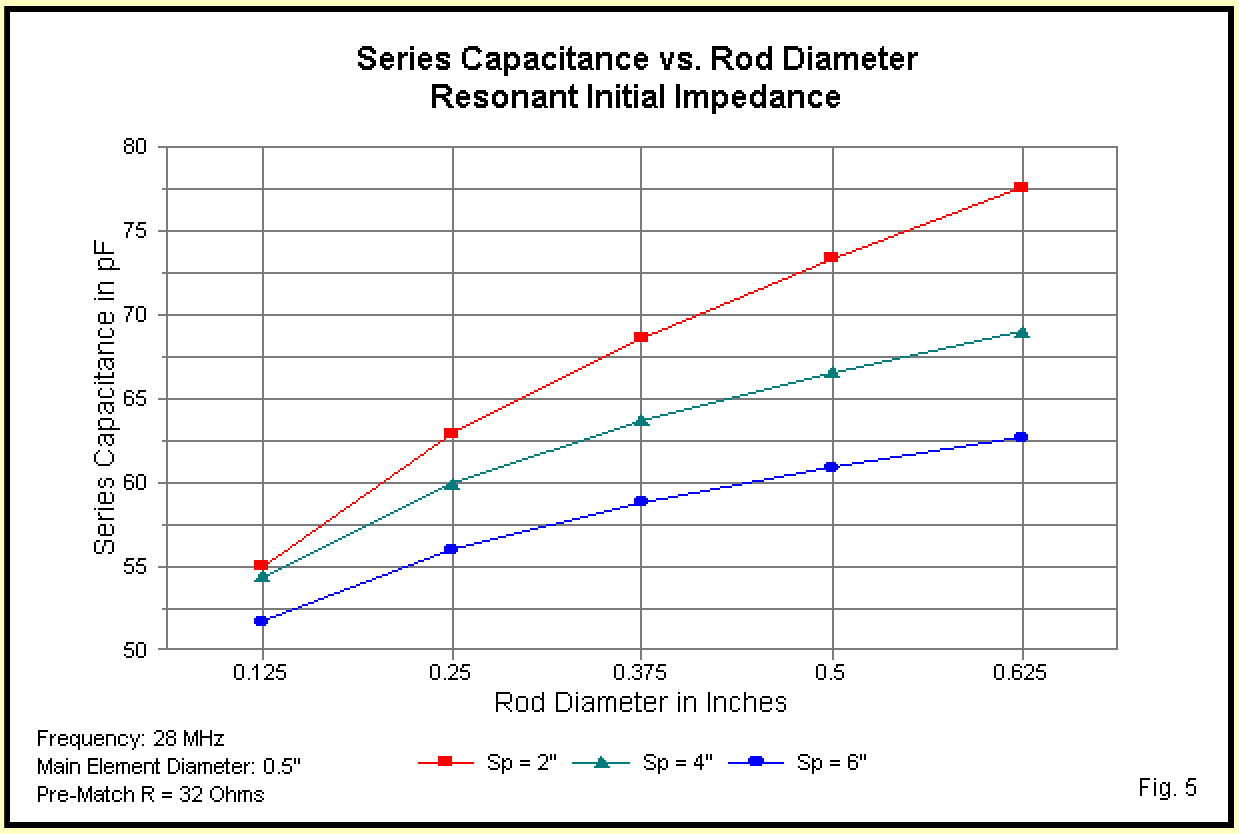


Fig. 4 graphs the outcome of the test for the resonant model with respect to the length of the gamma rod. (The tabular data appear in the original article.) The graph uncovers two interesting results. First, the modeled gamma rod undergoes almost no change in length, regardless of the ratio between the element and rod diameters. This outcome runs contrary to the trends shown by calculation systems. More important for our work here, it suggests that further modeling need not be concerned with the element-to-rod diameter ratio during first-order investigations into modeled gamma trends.

The second result is the regularity of the change in gamma-rod length with increasing spacing. The gamma rod length is inversely proportional to the spacing, but not in a simple arithmetic fashion. The open question is whether the proportions will hold for other initial impedance values, including those containing a significant reactive component.



Virtually every gamma match requires a series reactance to compensate for the remnant feedpoint inductive reactance. All models placed the series capacitance at the feedpoint, although physical construction practices may vary from this position. **Fig. 5** shows the progression of series capacitance values for the three spacing values, with the variations in the element-to-rod diameter ratio. Here, the curves are not linear. It is possible that the curves might meet for any reasonable spacing value with a gamma rod that is very thin. However, as the rod becomes thicker, the required series capacitance varies inversely according to spacing and directly with an increasing rod diameter.

I repeated the same sequence of models using the beam design that had a non-resonant feedpoint impedance. The feedpoint impedance phase angle approaches 41 degrees, which we may record as a very significant departure from resonance. However, the modeling procedures followed the same steps as used for the resonant model. The graph of the modeled gamma lengths appears in **Fig. 6**. (Once again, the full tabular data appear in the original article.)

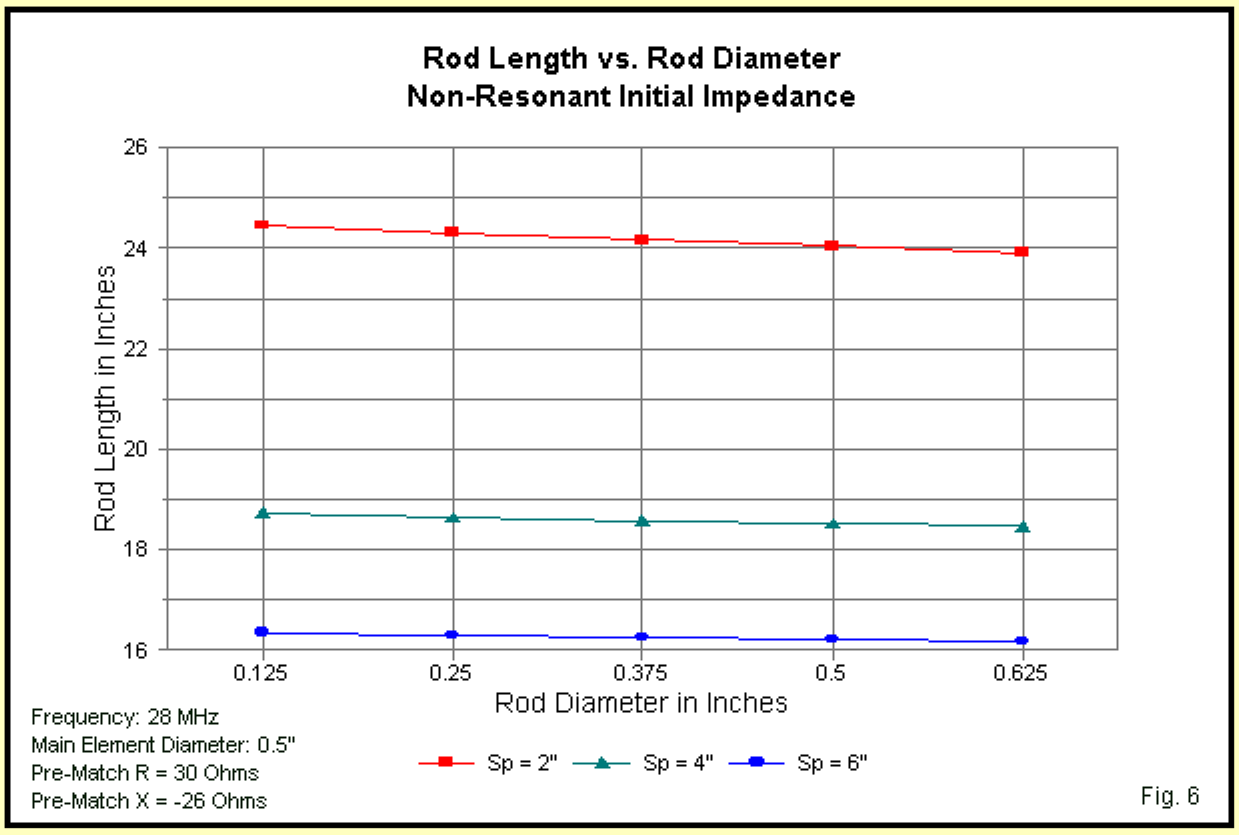


Fig. 6

The curves for each spacing increment show a definite "tilt" and become shorter as the gamma rod becomes thicker. However, the amount of length change for the change in the element-to-rod ratio is quite small: a 2% length change for a ratio change of 5:1. This result suggests that one might explore other directions in gamma-match variables by using a single element-to-rod ratio with confidence that the results for other ratios would not jeopardize the validity of the trends uncovered.

In addition, the change in gamma length for the changes in spacing follows very closely the relationships applicable to the resonant model. This result is also useful for further work, since it implies that one might use a single spacing value for further work and later derive conversion equations for transferring the results to other spacing values. The numerical values might change, but the trends would be reliable.

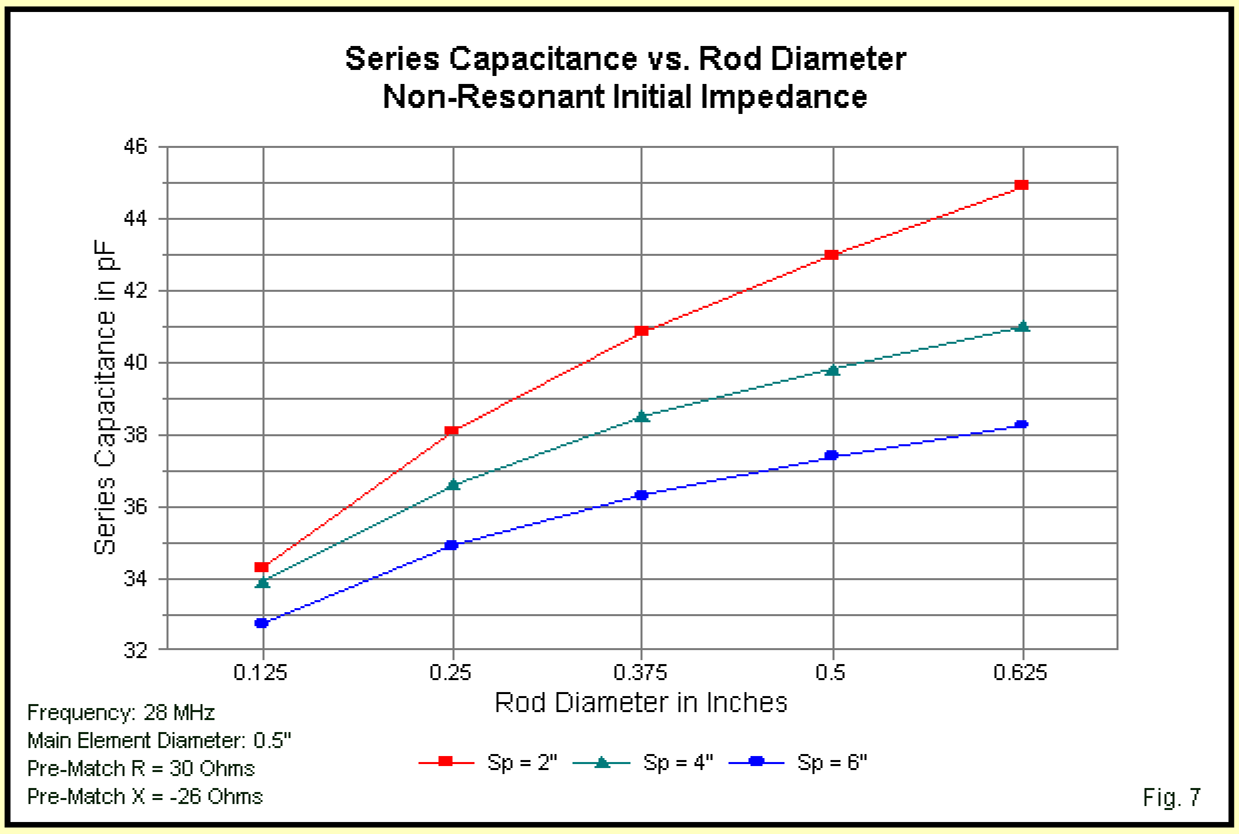


Fig. 7

The shapes of the curves for the required series capacitance in **Fig. 7** are virtually identical to those for the resonant model in **Fig. 5**. For all three spacing values, the resonant model required series capacitance values about 1.6 times higher than the ones for the non-resonant model using the thinnest gamma rod. The ratios only grow to between 1.7 and 1.8 using the fattest gamma rod. Within broad but usable limits, then, we may rely upon the trends of other modeling directions to be indicative of all spacing values and all element-to-rod ratios, even if we restrict ourselves to a single element-to-rod ratio and a single spacing value.

One of the most interesting results to emerge from the initial models of gamma matches at 28 MHz involved a rudimentary exploration of what happens if we systematically vary the initial feedpoint impedance between a fairly large capacitive reactance and a fairly large inductive reactance. To sample that situation, I varied the driver lengths of the pre-match models to arrive at impedances values that have nearly 26-Ohm reactances and nearly 13-Ohm reactances--of both types--with the resonant model at the center. To create these models, I varied the driver length until I reached acceptable feedpoint values and froze the dimensions at each step. This procedure is slightly inexact, since the resistive component will vary a small amount as the driver length changes without varying the other beam dimensions. However, for the purpose of looking at some basic trends, the variations in resistance are relatively harmless. To reduce the work involved, I checked the results using a constant 4" spacing between the element and the rod and looked at 0.125" and 0.375" gamma rod diameters. (The tabulated data appear in the original article.)

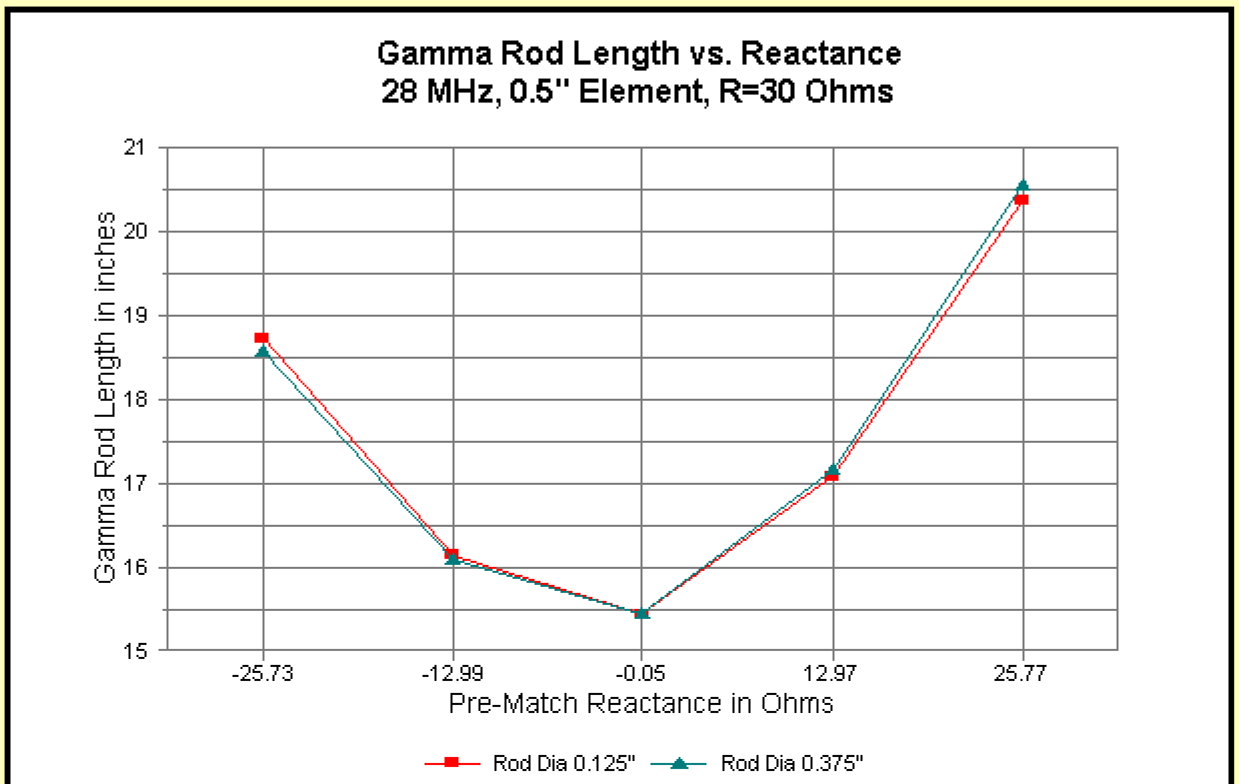


Fig. 8

With respect to gamma-rod length, as shown in **Fig. 8**, the size of the gamma rod makes virtually no difference. More significant is the shape of the curve itself. First, the shortest gamma-rod length occurs at or close to an initial resonant feedpoint. As we add either capacitive or inductive reactance to the initial feedpoint impedance, we require a longer gamma rod. This trend runs counter to results that we might obtain from calculation systems. Extant systems tend to show a continuous increase in gamma-rod length for the entire sequence of initial impedance values.

Also interesting is the tilt of the curve. The tilt might be a function of at least two phenomena. First, it might be a result (wholly or partially) of the rising resistive component of the initial impedance. Second, it might be a function of that fact that the shortest gamma-rod length does not occur at resonance, but perhaps on the capacitive side of resonance. Hence, we have an open question that deserves further investigation.

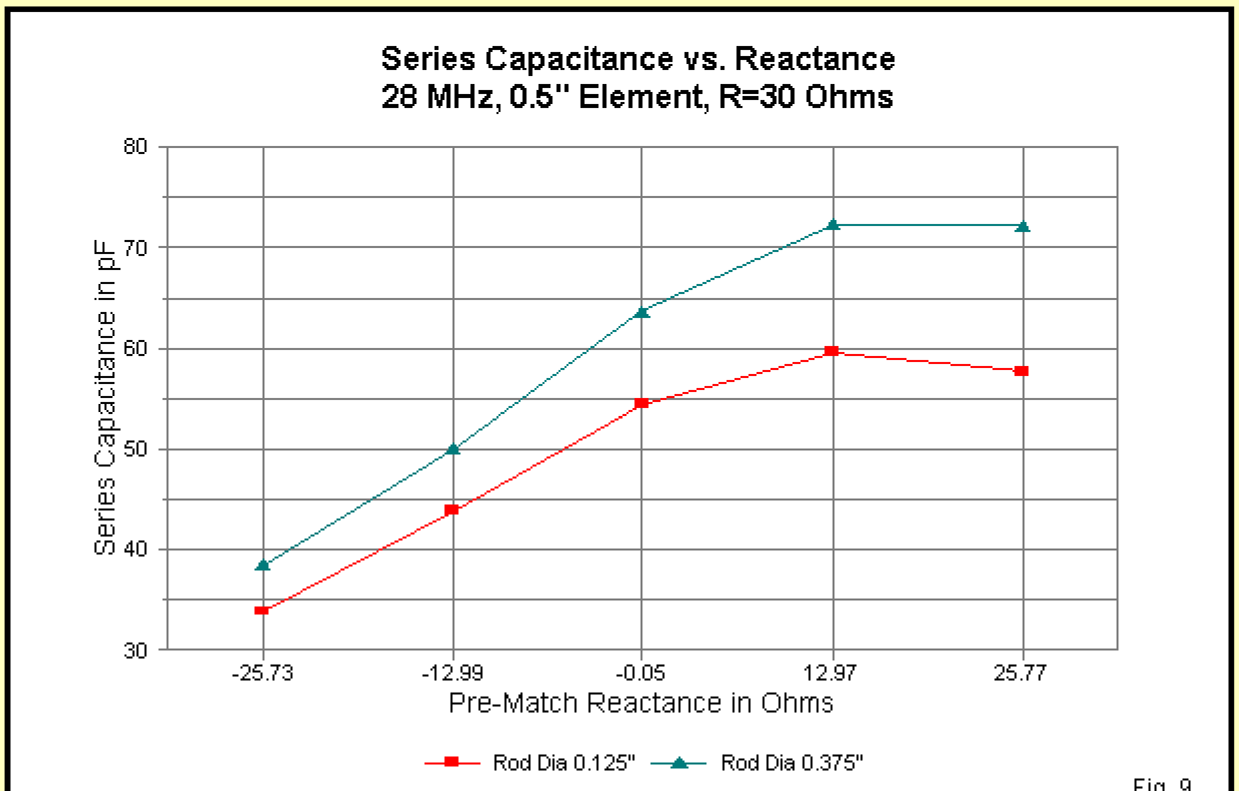


Fig. 9

As we would expect from the previous trends in modeled gamma match assemblies, the required series capacitance increases as we increase the gamma-rod diameter. **Fig. 9** shows the degree of increase as it varies according to the initial feedpoint reactance. Of equal interest is the fact that the required series capacitance reaches a peak value at the intermediate inductive reactance, and then begins to decline. The decline is greater for the thinner gamma rod than for the thicker one. Hence, we are once more left with a question of whether the peak occurs at the same initial feedpoint reactance in both cases.

We may add to these questions a further one: do the trends that we found in the gamma models apply equally to a wide range of potential initial feedpoint impedance values? The initial results suggest that we need a broader study of modeled gamma dimensions. We may set aside questions of gamma rod diameters and spacing and perhaps usefully focus on gamma assembly dimensions as we systematically vary the feedpoint impedance.

Basic Parameters of a Second Gamma Modeling Study

The added investigations into gamma-match behavior as modeled in Antenna Model's version of MININEC began with a different premise than the one used for the initial studies. The fundamental model properties should be transferable to any frequency with ease. Indeed, it might be possible to codify the results via regression analysis into design equations. Although this potential did not materialize, it did establish the parameters of the models.

The design frequency selected was at the middle of the span of frequencies in which we typically find gamma matches. For precision, I selected 29.97925 MHz, which we may round to 30 MHz. At the design frequency, every meter is 0.1 wavelength. Hence, all dimensions are metric. For the initial models in this group, we shall use a constant spacing: 0.1 m (3.937"), again, close to the 4" spacing used as a base line in the first series. The gamma rod will have the same diameter as the main element.

One important reason for freezing some of the model dimensions is to permit a survey of others. The initial models in this new study used a range of element and gamma-rod diameters ranging from 1 mm to 31.623 mm. Although the range may seem strange at first sight, the steps (1, 3.1623, 10, and 31.623) are equivalent to base-10 logarithms of -4 through -2.5 as a function of wavelength. The range of the coverage is from close to 0.04" (AWG #18 wire) up to nearly 1.25". Hence, the range of element diameters does not extend on either end very far beyond the range of materials from which we find gamma-match applications in the test frequency region (10 meters). The second axis of the survey involved a span of initial resonant element impedances. Although gamma matches may cover a wider range, 15 through 60 Ohms seemed to be a good range for conversion to a target feedline impedance of 50 Ohms. Indeed, it was possible to create initial 2-element Yagis with the desired feedpoint impedances, as shown in **Table 1**. As in previous models, the initial beams, when gamma-matched, produced a 50-Ohm driver impedance +/- 0.1 Ohms for both resistance and reactance.

1. Basic Resonant Models						Table 1
Frequency: 29.97925 MHz			Basic dimensions in meters			
Reflector length fixed at +/-0.25 m						
Z (R)	Dia mm	Dia in	Len Dr	Sp: D-R	R	X
15	1	0.0394	2.4063	0.790	15.00	-0.03
	3.1623	0.1245	2.3879	0.780	15.01	0.06
	10	0.3937	2.3600	0.764	15.02	0.01
	31.623	1.2450	2.3175	0.746	15.05	0.07
30	1	0.0394	2.3830	1.216	30.00	0.02
	3.1623	0.1245	2.3607	1.211	30.05	-0.05
	10	0.3937	2.3283	1.200	30.06	0.01
	31.623	1.2450	2.2795	1.186	30.01	-0.03
45	1	0.0394	2.3730	1.605	45.00	0.01
	3.1623	0.1245	2.3496	1.603	44.99	-0.06
	10	0.3937	2.3160	1.598	45.02	0.05
	31.623	1.2450	2.2660	1.592	45.01	0.01
60	1	0.0394	2.3724	2.008	60.03	0.02
	3.1623	0.1245	2.3496	2.010	60.00	0.01
	10	0.3937	2.3168	2.010	59.99	0.03
	31.623	1.2450	2.2690	2.01	60.00	-0.01
Notes:	Length in meters is for a half element; read as +/-Len.					
	R is within +/-0.1 Ohms of Z(R), X is within j+/-0.1 Ohms of 0.					
	Z(R) = target pre-match feedpoint impedance.					

In all cases, I held the reflector at a length of exactly 0.5-wavelength. The spacing varied as needed to yield a resonant driver. **Fig. 10** shows the driver half-lengths required for each impedance level as the element diameter increased. Note that there is virtually no difference between the 45-Ohm and the 60-Ohm driver lengths for any given element diameter; the spacing alone is sufficient to create the impedance difference. In the development of these models, the actual performance of the resulting beam is not in question and was not recorded. For gamma-match considerations, only the feedpoint impedance is significant.

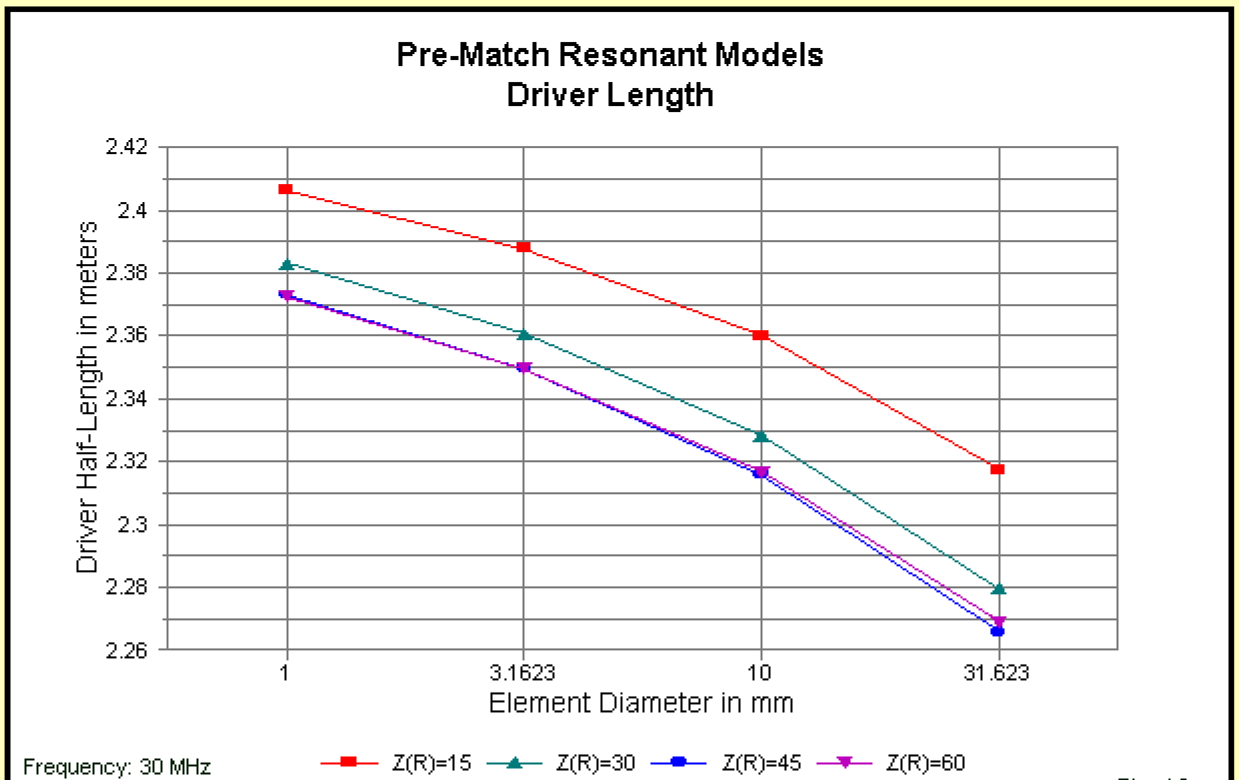


Fig. 10

Fig. 11 examines the required gamma rod lengths for each impedance level as we increase the element diameter. The curves show two results. First, the use of logarithmic increments results in relatively tame curves without requiring an unnecessarily large number of steps (and models). Second, the curves, while appearing to be congruent, do not achieve sufficient coincidence to allow effective regression analysis into a single set of design equations.

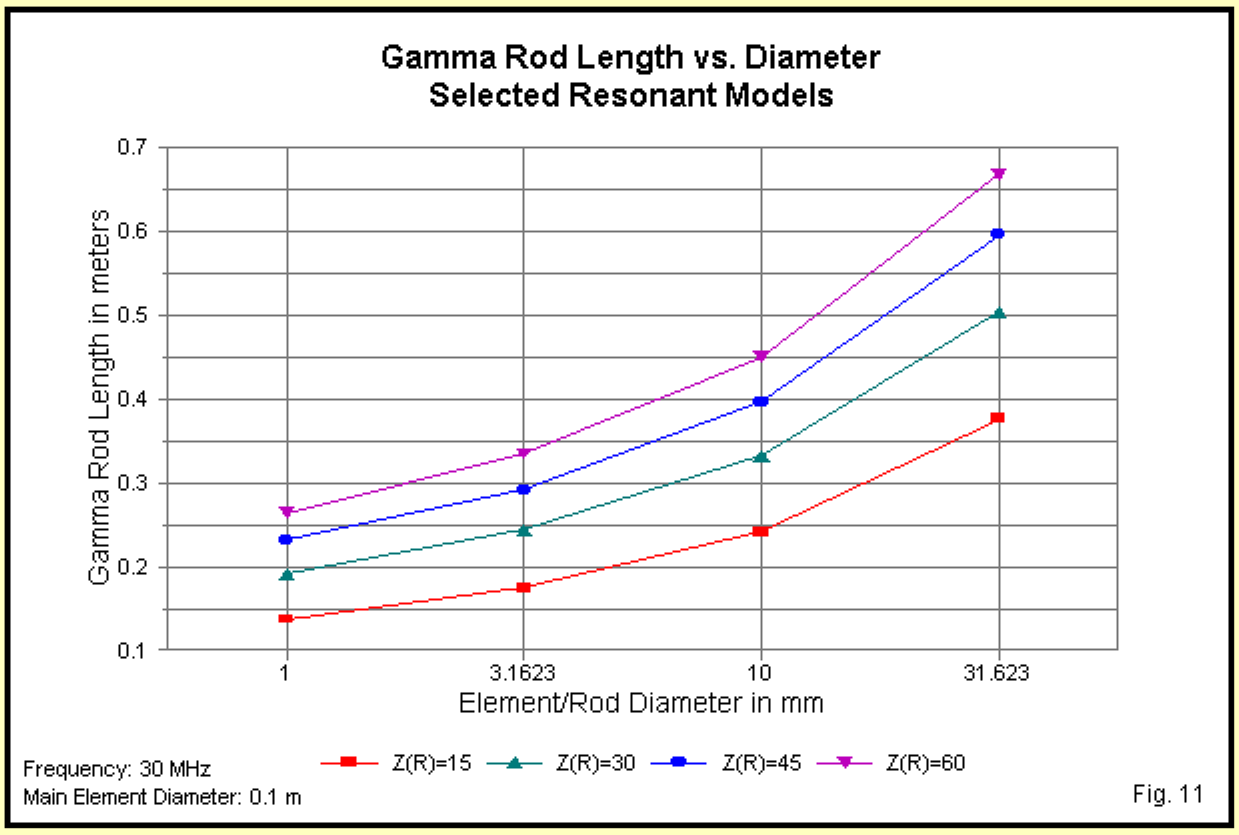


Fig. 11

Table 2 shows the data set behind the curves in **Fig. 11** and following graphs. The table includes a column listing the AGT score of each model. The AGT score improves toward an ideal value of 1.0000 as the number of segments is set to yield equal segment lengths along the driver. However, unlike the similar test in NEC, we cannot use the AGT value to correct the impedance value. Changing the proportions of segments in the gamma section and the remainder of that element half might not change the AGT at all or only by 0.0001. However, the gamma feedpoint impedance might change by as much as 2 Ohms. AGT values of 1.0000 are rare, since the gamma segment count can only increase by an integer. In many cases, the truly ideal number of segment would be a decimal value, resulting in a small but definite departure from equal-length segments along the driver as I put in place the closest integer value. In all cases, the gamma side of the driver used 50 segments.

2. Initial Gamma Match Models				Subdivided by Z(R)					Table 2
Frequency: 29.97925 MHz			Basic dimensions in meters						
Gamma rod diameter = main element diameter.					Gamma-rod spacing = 0.1m (3.937").				
Z (R)	Dia mm	Dia in	Gr Len m	Gr Len in	R	X (C=0)	CpF	X (CpF)	AGT
15	1	0.0394	0.1368	5.386	49.99	72.06	73.70	0.03	1.0076
	3.1623	0.1245	0.1747	6.878	50.05	67.37	78.80	0.00	1.0090
	10	0.3937	0.2417	9.516	50.04	64.07	84.20	0.02	0.9981
	31.623	1.2450	0.3762	14.811	50.06	58.66	90.60	0.06	0.9982
30	1	0.0394	0.1912	7.528	50.00	93.73	56.60	-0.07	0.9996
	3.1623	0.1245	0.2434	9.583	50.03	89.30	59.50	0.08	0.9975
	10	0.3937	0.3315	13.051	50.08	84.44	62.80	-0.09	0.9989
	31.623	1.2450	0.5035	19.823	50.09	78.81	67.40	0.04	0.9996
45	1	0.0394	0.2315	9.114	50.05	110.72	47.95	0.00	1.0020
	3.1623	0.1245	0.2917	11.484	50.03	105.72	50.20	-0.03	0.9973
	10	0.3937	0.3967	15.618	50.09	100.51	52.80	-0.03	1.0017
	31.623	1.2450	0.5954	23.441	50.00	94.01	56.50	0.05	0.9994
60	1	0.0394	0.2646	10.417	50.03	124.88	42.50	-0.03	1.0052
	3.1623	0.1245	0.3350	13.189	50.03	119.45	44.45	0.01	0.9988
	10	0.3937	0.4506	17.740	50.07	113.83	46.60	-0.09	1.0007
	31.623	1.2450	0.6682	26.307	50.01	106.84	49.70	0.02	0.9999
Notes:	Z(R) = pre-match model impedance.								
	R is within +/-0.1 Ohms of 50 Ohms, X (CpF) is within j+/-0.1 Ohms of 0.								
	AGT = Average Gain Test score; 1.0000 is ideal.								

As the table shows, each gamma length and accompanying series capacitor produced a feedpoint impedance of 50-Ohms resistive +/-0.1 Ohm of resistance or reactance. It is useful to examine the data by re-grouping it according to element diameters so that each curve represents the progression of resonant initial driver impedance values. **Fig. 12** provides a graphic perspective of the gamma length when viewed from the altered perspective.

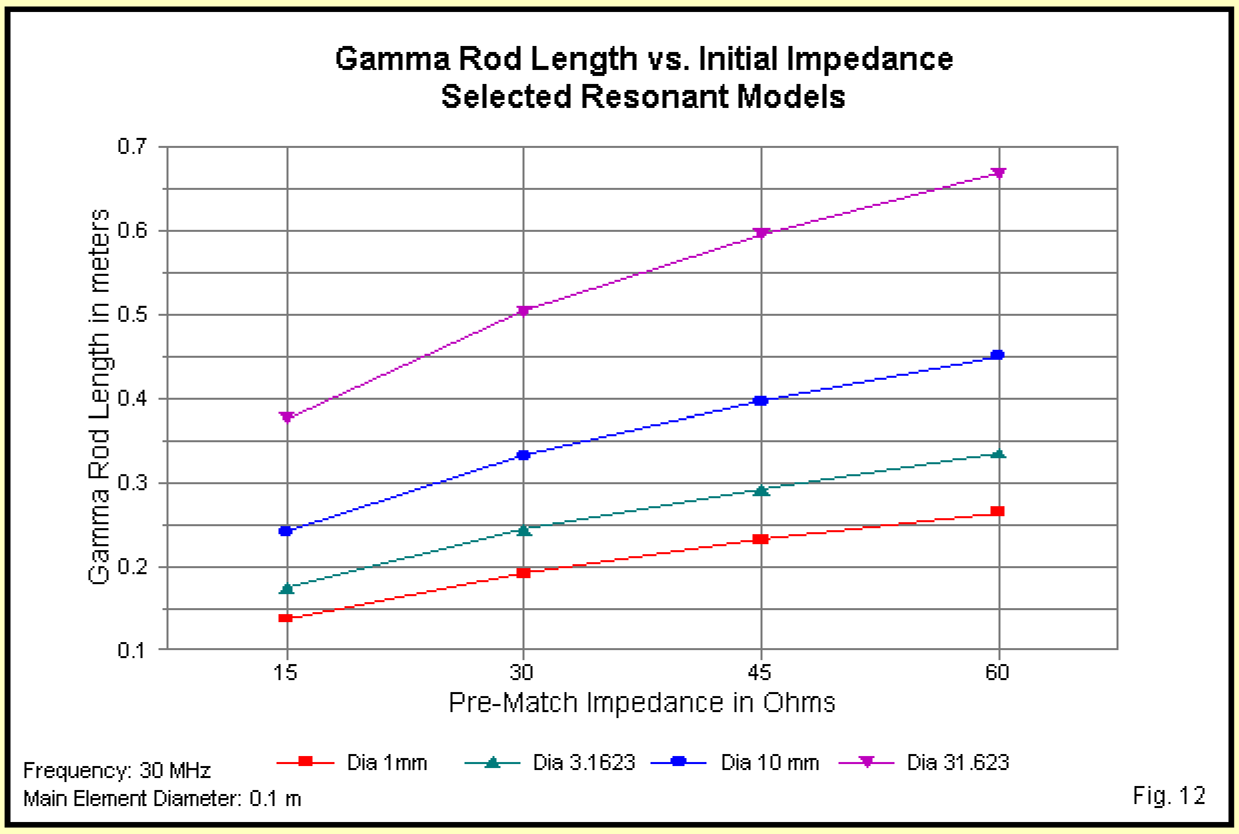


Fig. 12

As we increase the element diameter, the curve of gamma lengths becomes steeper, increasing with the initial feedpoint impedance. For each curve, the slope decreases as the initial feedpoint impedance comes closer to the target impedance, although the required length continues to increase. **Table 3** provides a reference table of the data in the graph, re-grouped for easy correlation.

2a. Initial Gamma Match Models				Subdivided by element diameter					Table 3
Frequency: 29.97925 MHz			Basic dimensions in meters						
Gamma rod diameter = main element diameter.					Gamma-rod spacing = 0.1m (3.937").				
Dia mm	Dia in	Z(R)	Gr Len m	Gr Len in	R	X (C=0)	CpF	X (CpF)	AGT
1	0.0394	15	0.1368	5.386	49.99	72.06	73.70	0.03	1.0076
		30	0.1912	7.528	50.00	93.73	56.60	-0.07	0.9996
		45	0.2315	9.114	50.05	110.72	47.95	0.00	1.0020
		60	0.2646	10.417	50.03	124.88	42.50	-0.03	1.0052
3.1623	0.1245	15	0.1747	6.878	50.05	67.37	78.80	0.00	1.0090
		30	0.2434	9.583	50.03	89.30	59.50	0.08	0.9975
		45	0.2917	11.484	50.03	105.72	50.20	-0.03	0.9973
		60	0.3350	13.189	50.03	119.45	44.45	0.01	0.9988
10	0.3937	15	0.2417	9.516	50.04	64.07	84.20	0.02	0.9981
		30	0.3315	13.051	50.08	84.44	62.80	-0.09	0.9989
		45	0.3967	15.618	50.09	100.51	52.80	-0.03	1.0017
		60	0.4506	17.740	50.07	113.83	46.60	-0.09	1.0007
31.623	1.245	15	0.3762	14.811	50.06	58.66	90.60	0.06	0.9982
		30	0.5035	19.823	50.09	78.81	67.40	0.04	0.9996
		45	0.5954	23.441	50.00	94.01	56.50	0.05	0.9994
		60	0.6682	26.307	50.01	106.84	49.70	0.02	0.9999
Notes:	Z(R) = pre-match model impedance.								
	R is within +/-0.1 Ohms of 50 Ohms, X (CpF) is within j+/-0.1 Ohms of 0.								
	AGT = Average Gain Test score; 1.0000 is ideal.								

Fig. 13 graphs the series capacitance data with separate curves for each initial impedance level. All curves show a rising series capacitance as we increase the element diameter. The lowest initial feedpoint impedance requires the highest series capacitance values. Once more, the curves are nearly but not quite congruent.

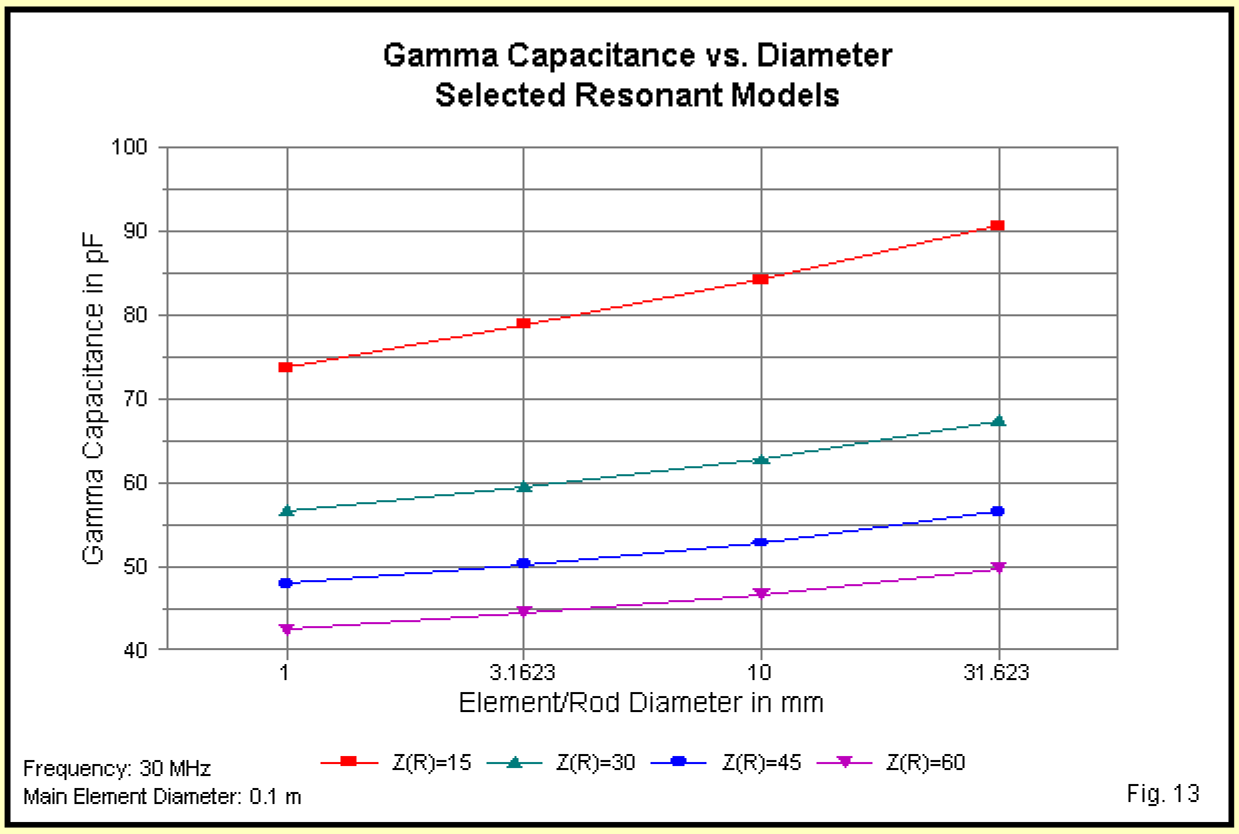


Fig. 13

If we re-group the data by element diameters, we can see the degree of required capacitance decrease as we increase the initial feedpoint impedance for all wire diameters. The graph in **Fig. 14** has a quite different appearance than the one in **Fig. 13**, although both graphs cover the same overall data set. Looking at only one of the two graphs might well leave a misimpression of the changes that occur from one step to the next.

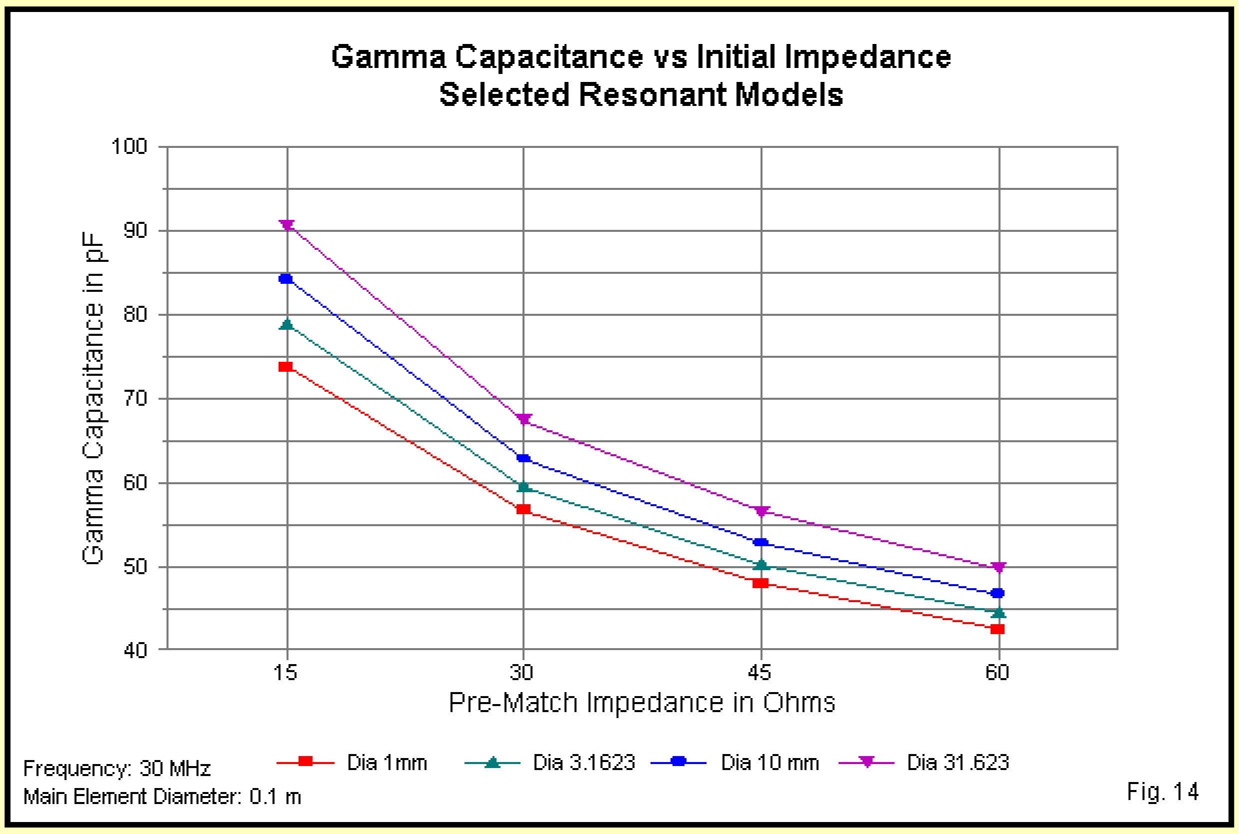


Fig. 14

The data that we have surveyed expands previous examinations of gamma assembly models by expanding the range of resonant initial feedpoint impedance values. The cost of expanding the impedance range was a restriction to a single gamma-rod spacing: 0.1 m. As well, the entire survey uses a uniform target impedance of 50 Ohms resistive. Nonetheless, the tabulated and graphed data provide insights into what MININEC models report about the required gamma rod length and the required series capacitance value across the range of resonant initial feedpoint resistance level that one is most likely to encounter in beam construction. By using graphs with alternating orientations, one might easily infer values for other initial resonant feedpoint impedance between 15 and 60 Ohms. As well, one might then scale the models to other frequencies, although the gamma spacing might become too large or too small at very wide excursions from the test frequency.

Varying the Initial Feedpoint Reactance

One important reason for expanding the range of initial feedpoint impedance values was to gain a better understanding of the consequences of varying the initial feedpoint reactance. To perform this further study, it was necessary to restrict at least one of the variables in the examination of basic parameters. I chose to freeze the element and gamma rod diameter at 0.01 m (0.3937"). In addition, the models in this collection use the 0.1-m spacing of the previous set at the same test frequency.

For each impedance level, I reset only the driver length to achieve the desired reactance values. In order to include more increments within the set, I used an increment of j8 Ohms of reactance for the models. The resulting set of models for each target impedance level includes 7 models with limiting reactance values of -j24 and +j24 Ohms. Because the driver length changes, the resistance value of the initial feedpoint impedance will change slightly from one end of the model span to the other for each target value. However, for simplicity, we may still find the tilted graphs both usable and perhaps instructive. **Table 4** tabulates the models in this set prior to the addition of gamma assemblies.

4. Basic Models: 2-Element Driver-Reflector Yagis						Frequency: 29.97925 MHz			Table 4
All Reflectors +/-2.50 m						Element Diameter 0.01m (0.3937")			
Z(R)	Nom X	Dr Len m	R	X	Z(R)	Nom X	Dr Len m	R	X
15	-24	2.3030	14.39	-23.96	45	-24	2.2638	41.97	-23.96
El Sp m	-16	2.3220	14.60	-15.98	El Sp m	-16	2.2812	42.96	-16.00
0.764	-8	2.3410	14.81	-7.99	1.598	-8	2.2986	43.98	-7.99
	0	2.3600	15.02	0.01		0	2.3160	45.02	0.05
	8	2.3790	15.23	8.03		8	2.3332	46.07	8.05
	16	2.3980	15.44	16.06		16	2.3503	47.14	16.03
	24	2.4170	15.65	24.10		24	2.3674	48.24	24.05
30	-24	2.2749	28.20	-24.00	60	-24	2.2646	55.75	-24.04
El Sp m	-16	2.2927	28.81	-16.02	El Sp m	-16	2.2820	57.13	-16.05
1.2	-8	2.3105	29.43	-8.02	2.01	-8	2.2994	58.55	-8.03
	0	2.3283	30.06	0.02		0	2.3168	59.99	0.03
	8	2.3461	30.71	8.08		8	2.3340	61.46	8.04
	16	2.3637	31.36	16.09		16	2.3511	62.96	16.03
	24	2.3812	32.02	24.08		24	2.3681	64.48	24.02
Notes:	Length in meters is for a half element; read as +/-Len.								
	Z(R) is the target resistance; Nom X is the target reactance.								
	R at X=0 is within +/-0.1 Ohms of Z(R), X is within j+/-0.1 Ohms of target value.								

As the table shows, I used the same +/-j0.1-Ohm limit in setting the driver length (the table shows half-lengths) for each model in each target impedance group. Interestingly, the span of resistance values from -j24 Ohms to +j24 Ohms does not increase in proportion to the target impedance. The maximum target impedance is 4 times the minimum value. However, the 15-Ohm span is 1.26 Ohms, while the 60-Ohm span is 8.73 Ohms, a ratio of nearly 7:1. For reference, **Fig. 15** shows the driver lengths that accompany the changes in reactance for each target impedance group.

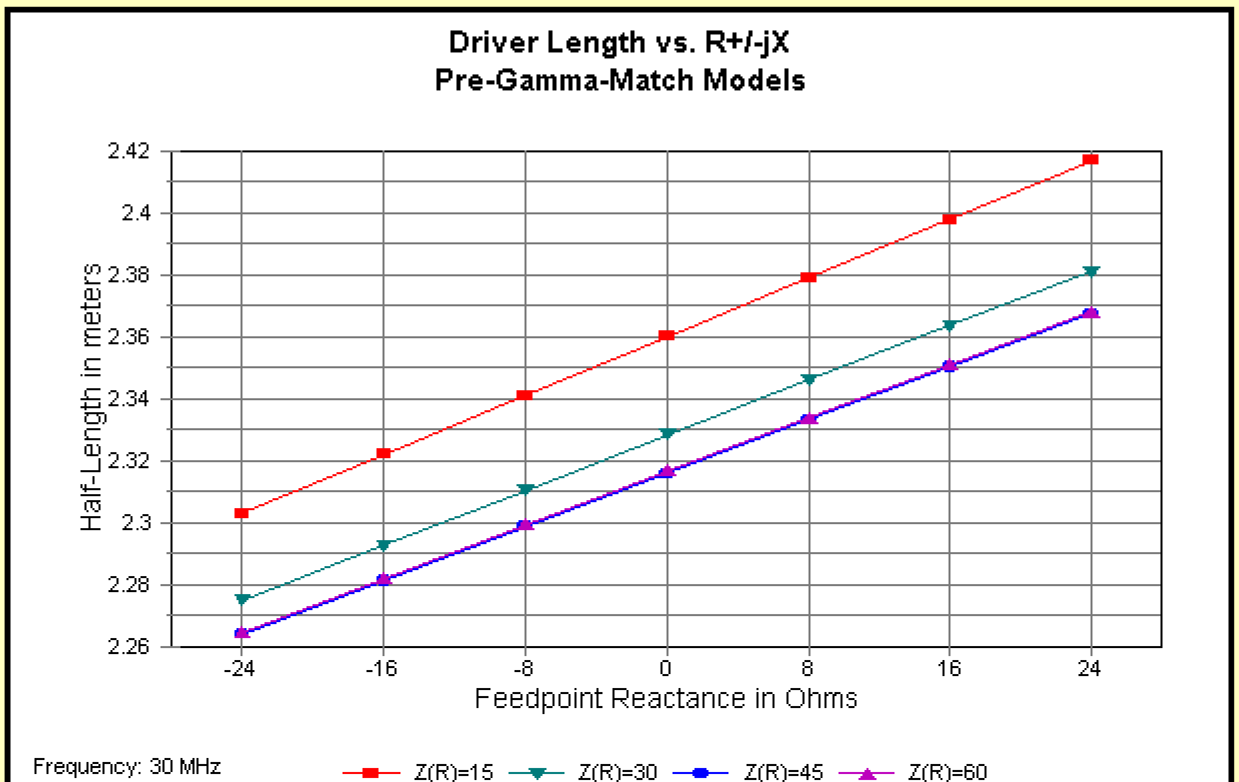


Fig. 15

As we saw for the case of resonant initial impedances, there is virtually no difference between the driver lengths for 45 and for 60 Ohms, regardless of the reactance. Indeed, were it not for the slight changes in the resistive component of the initial impedance, the graphed lines might be arithmetically linear.

For each of the 28 initial models, there is an accompanying gamma-match model. Each of these models uses a gamma rod length and series capacitance that brings the gamma feedpoint impedance to 50 Ohms resistive within the usual limits imposed on the exercise. **Table 5** provides a record of the data in progressive form. The gamma rod length was varied until the resistive component was 50 Ohms and the reactance was recorded. Although one might simply use this information to calculate the required series capacitance, I modeled it in place and recorded both the capacitance value and the remnant reactance. The AGT scores are also part of the tabular record.

5. Gamma-Matched Models				Frequency: 29.97925 MHz				Table 5
All Reflectors +/-2.50 m				Element and Gamma-Rod Diameter 0.01m (0.3937")				
Element-to-Gamma-Rod Spacing 0.1 m (3.937") center-to-center								
Z(R)	Nom X	Gr Len m	Gr Len in	R	X (C=0)	CpF	X (CpF)	AGT
15	-24	0.4097	16.130	50.02	182.88	29.03	0.00	1.0003
El Sp m	-16	0.3313	13.043	50.01	137.70	38.56	0.03	0.9988
0.764	-8	0.2653	10.445	50.07	95.70	55.50	0.05	1.0033
	0	0.2417	9.516	50.04	64.07	84.20	0.02	0.9981
	8	0.2790	10.984	50.02	45.33	117.00	-0.04	1.0012
	16	0.3643	14.343	50.06	38.58	137.50	-0.03	1.0022
	24	0.4780	18.819	50.06	37.52	141.50	0.00	1.0002
30	-24	0.3970	15.630	50.07	142.05	37.37	-0.01	1.0010
El Sp m	-16	0.3575	14.075	50.01	118.53	44.80	0.03	1.0008
1.2	-8	0.3354	13.205	50.06	98.88	53.70	0.02	0.9980
	0	0.3315	13.051	50.08	84.44	62.80	-0.09	0.9989
	8	0.3500	13.780	50.01	75.46	70.40	0.05	0.9967
	16	0.3868	15.228	50.06	71.69	74.00	-0.05	0.9988
	24	0.4375	17.224	50.04	71.60	74.10	-0.04	0.9990
45	-24	0.4250	16.732	50.03	135.23	39.25	-0.03	0.9981
El Sp m	-16	0.4044	15.921	50.02	120.75	43.95	-0.03	1.0003
1.598	-8	0.3945	15.532	50.05	109.07	48.70	0.06	1.0016
	0	0.3967	15.618	50.09	100.51	52.80	-0.03	1.0017
	8	0.4102	16.150	50.01	95.02	55.90	0.05	1.0007
	16	0.4345	17.106	50.04	92.40	57.50	0.07	0.9987
	24	0.4662	18.354	50.07	92.31	57.49	-0.03	1.0003
60	-24	0.4600	18.110	50.08	137.27	38.70	0.09	0.9992
El Sp m	-16	0.4490	17.677	50.03	127.32	41.70	0.01	1.0003
2.01	-8	0.4456	17.543	49.99	119.44	44.45	0.01	1.0008
	0	0.4506	17.740	50.07	113.83	46.60	-0.09	1.0007
	8	0.4623	18.201	49.99	110.17	48.20	0.03	1.0000
	16	0.4812	18.945	50.06	108.52	48.90	-0.05	0.9989
	24	0.5040	19.843	50.00	108.36	49.00	0.02	1.0008
Notes:	Z(R) and Nom X = pre-match model impedance.							
	R is within +/-0.1 Ohms of 50 Ohms, X (CpF) is within j+/-0.1 Ohms of 0.							
	AGT = Average Gain Test score; 1.0000 is ideal.							

Graphs for the required gamma lengths are perhaps more vivid in showing the changes as we move from one initial impedance level to the next. **Fig. 16** provides the required information.

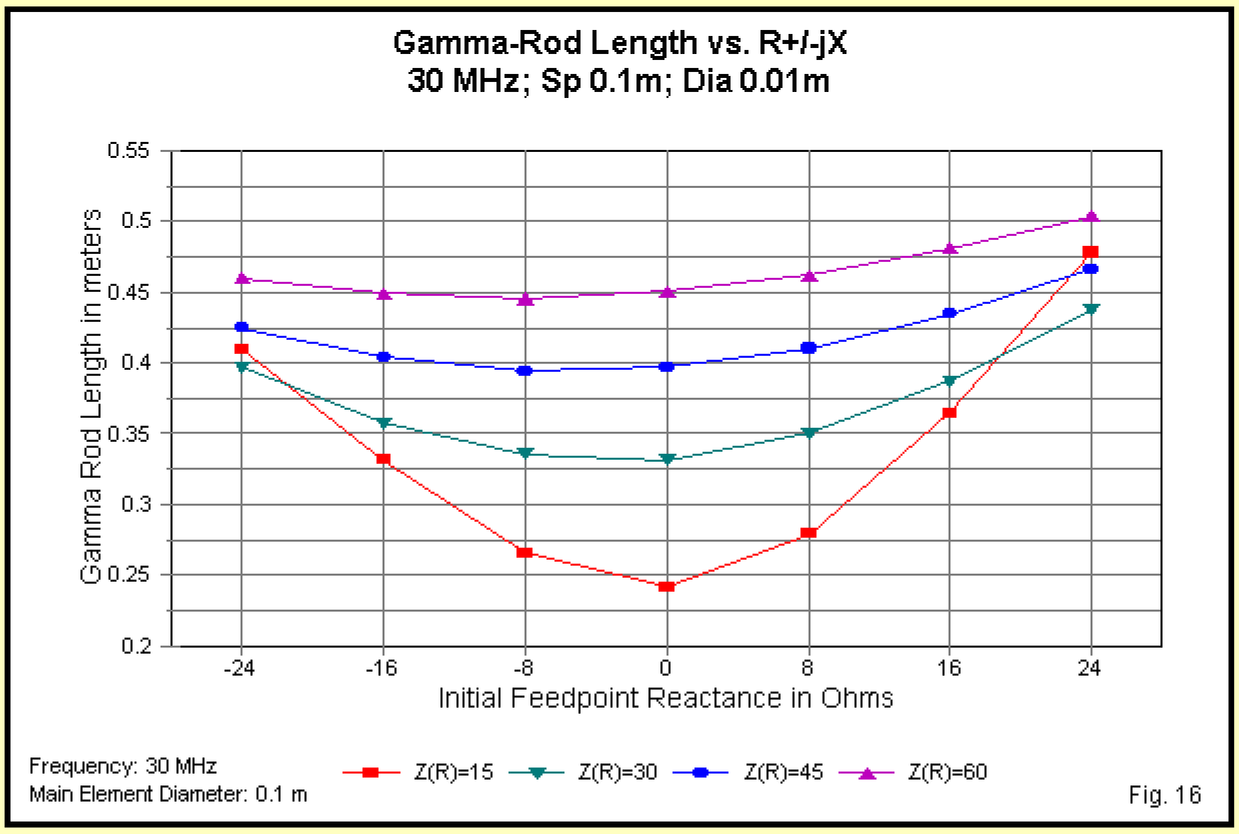


Fig. 16

The graph uses enough increments and enough initial impedance levels to be instructive, at least so far as we may interpret the MININEC models. First, the higher the initial impedance level, the shallower will be the curve of required gamma-rod lengths from -j24 to +j24 Ohms reactance. The ratio of maximum gamma length to minimum gamma length is about 4 times greater for the 15-Ohm curve than for the 60-Ohm curve. It is likely no accident that the ratio of initial impedance levels is also 4:1. It is probable that the curves would better approach congruence had we set up the exercise by reference to the impedance phase angle rather than using definite values of reactance.

Second, the curves strongly indicate that the shortest gamma rod length does not occur precisely at a resonant initial feedpoint impedance. As we increase the initial target impedance toward 60 Ohms, we find that the lowest recorded gamma lengths occur with an initial feedpoint reactance of -j8 Ohms. It is very likely that the lower two impedance levels would show the shortest gamma-rod lengths with reactances somewhere between j0 and -j4 Ohms.

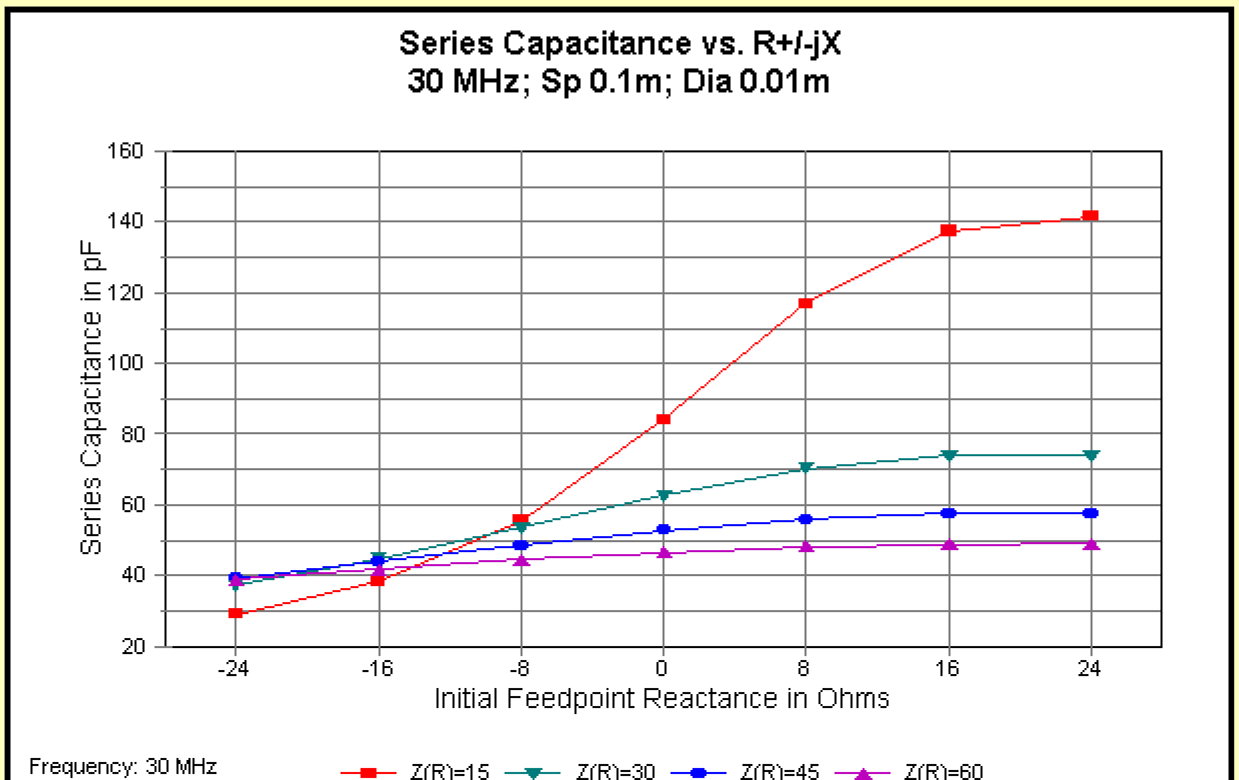


Fig. 17

Fig. 17 shows what happens to the required series capacitance values as we move from one target impedance group to the next and as we change the initial feedpoint reactance in j8-Ohm increments. In all cases, we find a rising curve. However, by including the curve for the 15-Ohm target impedance level, we clearly see the S-shape of the curve, a detail that might elude us had we used only values closer to the feedline impedance. The curves meet and cross in the region of reasonably high capacitive reactance.

In general, the models suggest that the closer the initial impedance is to the feedline impedance, the less critical will be the dimensions of the gamma assembly. Small changes in gamma length and small changes in the series capacitance will alter the gamma feedpoint performance less and less as the initial impedance is at or above about 30 Ohms. As well, the initial feedpoint reactance will have a smaller impact upon the required rod and capacitor values if the initial resistive component is greater. In this region of initial feedpoint impedance values, construction variables will very quickly outweigh differences among modeled variations. However, as we encounter initial impedances below 30 Ohms, small variations in reactance, gamma length, and series capacitance can very significantly affect the gamma feedpoint impedance and its match to the feedline.

Tentative Conclusions

These notes only tell us what carefully constructed MININEC models report. In each case, I have had to restrict the number of operative variables in order to arrive at doable modeling tasks. Even so, the model collection passed 150 files long ago.

The data does reveal useful trends within the modeled assemblies. Nevertheless, the models have two shortcomings of which we must be constantly aware. First, the models presume an idealized gamma structure that may differ from actual gamma assemblies. **Fig. 18** indicates some of the points of difference.

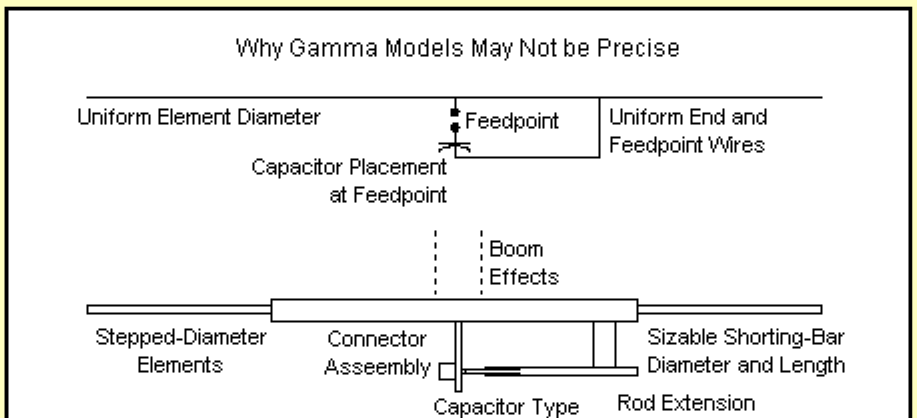


Fig. 18

It is possible to model some of the physical variations between the ideal configurations that we have used for systematic data and actual gamma assemblies. Preliminary models suggest that the rod extension is not a major difficulty if the models are reasonable approximations of the actual gamma assembly. I added rod extensions beyond the far end of the gamma assembly in 50-mm increments. At an extension length of 150 mm (about 6"), selected models showed only about 1.5 Ohms difference between the feedpoint impedances of the ideal assembly and of the extended assembly. The series capacitance required no change.

We may also change the modeled diameter of the near- and far-end connector wires or bars with fair ease. Using models with a 0.01-m element and gamma-rod diameter, I varied the end wire diameters between about 3 mm (about 1/8") and 50 mm (about 1"). The required change in the gamma-rod length was only about 1%. The required capacitance change also fell into the 1% range.

Much more striking is the amount of change in both gamma-rod length and in the series capacitance value as we change the series capacitor position from its ideal location at the feedpoint. Antenna Model allows only limited locations for load positions, so I checked the ideal position, a capacitor location at the beginning of the gamma rod, and a position at the center of the rod. The last position coincides approximately with capacitors made from concentric tubes and hence distributed along the gamma-rod length. I used both a resonant and a non-resonant initial impedance for the sample checks. The models involve beams using 0.01-m diameter elements with a spacing of 0.12 wavelength. **Table 6** shows the results of these first samplings.

6. Gamma Dimensions vs. Series Capacitor Location					Frequency: 29.97925 MHz		
All Reflectors +/-2.50 m			Element and Gamma-Rod Diameter 0.01m (0.3937")				
Element Spacing: 01.20 m (0.12 wl)			Element-Rod Spacing: 0.1 m (3.937")				
a. Resonant Initial Impedance							
Capacitor Position		Gr Len m	Gr Len in	R	X	CpF	AGT
Pre-gamma model				30.06	0.02		0.9998
	C at feedpoint	0.3315	13.05	50.08	-0.09	62.80	0.9989
	C at corner of rod	0.3360	13.23	50.00	0.01	62.40	0.9982
	C at center of rod	0.3480	13.70	49.97	0.02	61.00	1.0029
Percent Change		4.98				2.95	
b. Non-Resonant Initial Impedance							
Capacitor Position		Gr Len m	Gr Len in	R	X	CpF	AGT
Pre-gamma model				28.20	24.00		
	C at feedpoint	0.3970	15.63	50.07	-0.01	37.37	1.0010
	C at corner of rod	0.4050	15.94	49.99	-0.05	36.70	1.0001
	C at center of rod	0.4345	17.11	50.02	-0.08	34.87	1.0015
Percent Change		9.45				7.17	
Notes:	R is within +/-0.1 Ohms of 50 Ohms, X (CpF) is within j+/-0.1 Ohms of 0.						
	AGT = Average Gain Test score; 1.0000 is ideal.						Table 6

The samples suggest that the degree to which a non-ideal capacitor position changes the gamma dimensions may vary with the amount of reactance in the initial beam impedance. However, in both sets, the trend is the same: the farther away from the feedpoint that we place the gamma capacitor, the greater will be the variation from the ideal configuration values for both the gamma rod length and the series capacitor. Most series capacitor designs can handle the variation within standard field adjustments. However, if we do not account for the capacitor position, we might discover that we need to re-construct the gamma rod to arrive at the desired target feedpoint impedance.

The second shortcoming of the ideal models continues the theme of construction discoveries. The models have not been subjected to careful comparisons with physical models that replicate the gamma features. Indeed, this difficulty is endemic to all gamma-match design systems. At best, they have been subjected only to spot checks. Hence, we cannot tell the difference between systematic and accidental coincidence of results.

Nevertheless, patient modeling has strongly suggested the presence of some trends in gamma behavior that we might easily have overlooked had we only used one of the calculation methods of obtaining gamma design values. As well, the modeling data is now available for comparison with the results of those methods. Hence, the modeling task has made at least a small contribution to the study of gamma matches.

Nevertheless, there remain many questions, even within the realm of gamma-match models. Does the model's insensitivity to changes in the ratio of the gamma rod diameter to the main element diameter hold up across the same span of target initial driver impedance values--and across the same span of reactance values? Does the seeming regularity of gamma rod changes also hold up across the range of target impedances and reactance variations?

What modeling may have to say to these questions--and others left in silence--will have to await one of two events. One possibility is the absorption of the task by another modeler. The other possibility is my own recovery from the fatigue that accompanies all extended adventures into systematic modeling.

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