FEED LINE LOSSES IN MICROSTRIP ANTENNA ARRAYS

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Abstract

An effect of the number of antenna array elements and element spacing on microstrip feed line losses is studied. The effect of substrate parameters of the microstrip feed line is also included in this investigation. The research is carried out in K_u-band.

1. INTRODUCTION

Because of their incontestable advantages (light weight, low volume, thin profile, conformal geometry, low fabrication cost, etc.) microstrip antennas replace currently conventional antennas for most applications especially in mobile communications. The major advantages of microstrip antennas are realized in applications that require moderate size arrays. In this case one may obtain a high antenna gain with relatevely small antenna array dimensions. The main problem in this approach is that the increase of number of antenna array elements leads to the increase of microstrip feed line losses and decrease of the antenna array gain.

In this study the effect of seven microstrip antenna array parameters on feed line losses is investigated as follows:

- number of antenna array elements N;
- frequency f;
- element spacing d;
- substrate thickness h;
- conductor thickness t;
- substrate reative dielectric constant ε_r;
- substrate dissipation factor $\tan\delta$.

2. THEORY

Figure 1 shows the geometry of a microstrip antenna array, and the geometry of a microstrip feed line is shown in Figure 2.

For a symmetrical parallel feed network, the number of radiating elements is

$$N = 2^n,\ n = 1, 2, 3, \ldots, \tag{1}$$

where n is an integer. On the other hand

$$N = N_x N_y, \tag{2}$$

where N_x and N_y are the number of antenna array elements in x- and y-axis respectively.

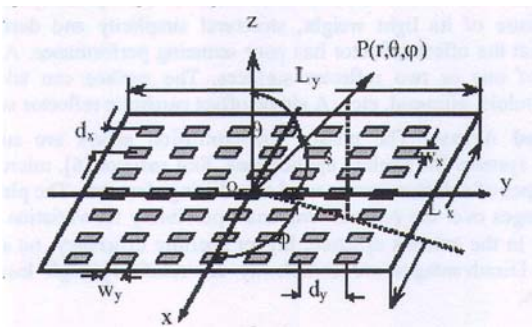

Figure 1. Geometry of a microstrip antenna array

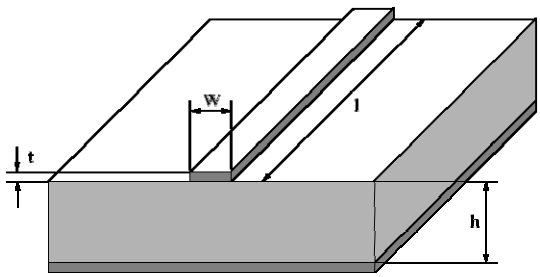

Figure 2. Geometry of a microstrip line

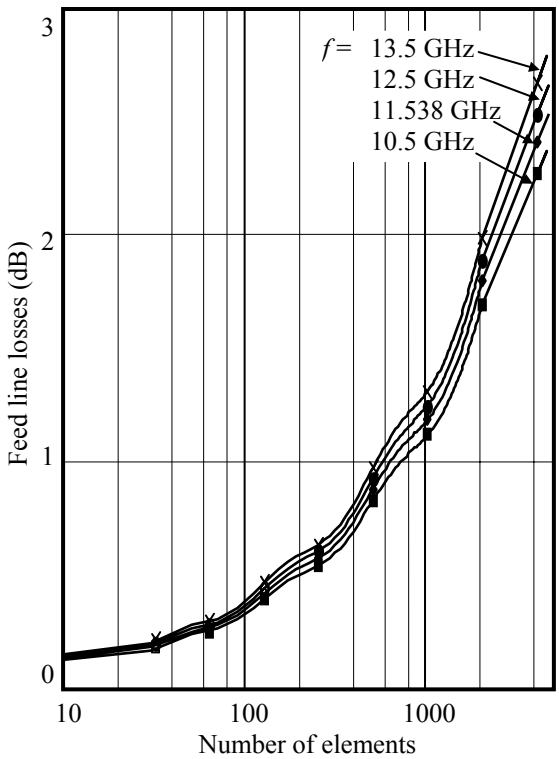

Figure 3. Feed line losses L versus number of elements N and frequency

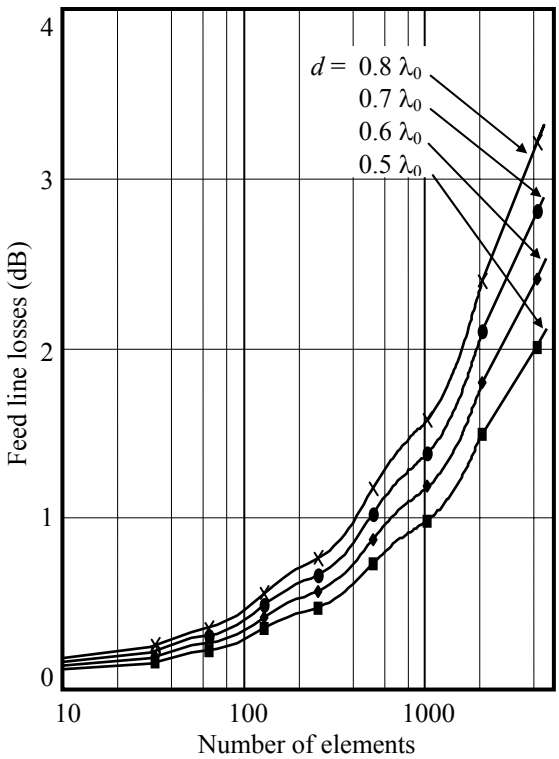

Figure 4. Feed line losses L versus number of elements N and element spacing d

If n is odd, $N_x \neq N_y$. Let $N_x > N_y$. Then

$$N_x = 2^{\frac{n+1}{2}},\ N_y = 2^{\frac{n-1}{2}},\ n = 1,3,5,\ldots \tag{3}$$

If n is even

$$N_x = N_y = 2^{\frac{n}{2}}, n = 2,4,6,... \tag{4}$$

The minimum length of the feed line (the connector is positioned in the antenna array centre) according to the Figure 1 is

$$l = \left(2^{\frac{n+1}{2}} - 1\right)\frac{d_x}{2} + \left(2^{\frac{n-1}{2}} - 1\right)\frac{d_y}{2}, \text{ where } n \text{ is odd,} \tag{5}$$

$$l = \left(2^{\frac{n}{2}} - 1\right)\left(\frac{d_x}{2} + \frac{d_y}{2}\right), \text{ where n is even, and} \tag{6}$$

d_x and d_y are the element spacing in x- and y-axis respectively.

In the case when $d_x = d_y = d$ the feed line length is defined by expressions

$$l = \left(2^{\frac{n-1}{2}} + 2^{\frac{n-3}{2}} - 1\right)d, n = 1,3,5,... \tag{5a}$$

$$l = \left(2^{\frac{n}{2}} - 1\right)d, n = 2,4,6,... \tag{6a}$$

The values of the number of antenna array elements and the feed line length for n = 1 to 12 are shown in Table 1.

The microstrip feed line losses L are defined by

$$L = \alpha l \text{ , dB} \tag{7}$$

where α is the attenuation coefficient. It has three components due to conductor (ohmic) losses (α_c), dielectric (substrate) losses (α_d) and losses due to radiation and propagation of surface waves and higher order modes (α_r) [1,2].

Table 1. Values of the number of antenna array elements and the feed line length

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
N_x	2	2	4	4	8	8	16	16	32	32	64	64
N_y	1	2	2	4	4	8	8	16	16	32	32	64
N	2	4	8	16	32	64	128	256	512	1024	2048	4096
l	0.5*d*	*d*	2*d*	3*d*	5*d*	7*d*	11*d*	15*d*	23*d*	31*d*	47*d*	63*d*

$$\alpha = \alpha_c + \alpha_d + \alpha_r \tag{8}$$

$$\alpha_c = 1.38A\frac{R_S}{hZ_0(f)}\frac{(32 - W_{eff}/h)^2}{(32 + W_{eff}/h)^2} \quad \text{for} \quad \frac{W}{h} \le 1 \tag{9}$$

$$\alpha_c = 6.1\times10^{-5} A \frac{R_S Z_0(f)\varepsilon_{reff}(f)}{h}\left[\frac{W_{eff}}{h} + \frac{0.667(W_{eff}/h)}{(W_{eff}/h)+1.444}\right] \text{ for } \frac{W}{h} \geq 1 \qquad (10)$$

and

$$\alpha_d = 27.3\frac{\varepsilon_r}{\varepsilon_r - 1}\frac{\varepsilon_{reff(f)} - 1}{\sqrt{\varepsilon_{reff(f)}}}\frac{\tan\delta}{\lambda_0}\ , \qquad (11)$$

where:

$$A = 1 + \frac{h}{W_{eff}}\left\{1 + \frac{1.25}{\pi}\ln\left(\frac{2\pi W}{t}\right)\right\} \text{ for } \frac{W}{h} \leq \frac{1}{2\pi} \qquad (12)$$

$$A = 1 + \frac{h}{W_{eff}}\left\{1 + \frac{1.25}{\pi}\ln\left(\frac{2h}{t}\right)\right\} \text{ for } \frac{W}{h} \geq \frac{1}{2\pi} \qquad (13)$$

$$R_S = \sqrt{\frac{\pi f_0 \mu_0}{\sigma_c}} \text{ is the surface conductor impedance} \qquad (14)$$

In the above expressions σ_c is the copper conductivity, W_{eff} is the effective feed line width, $\varepsilon_{reff}(f)$ and $Z_0(f)$ are frequency-dependent effective dielectric constant and characteristic impedance [1,3,4], and λ_0 is the free-space wavelength .

The radiation losses for a microstrip line become significant for figh frequencies. They may be ignored if [1]

$$f < 2.14\ (\varepsilon_r)^{0.25}/h_{[mm]},\ \text{GHz} \qquad (15)$$

To avoid an excitation of high modes in the feed line the substrate thickness should be chosen such that [2]:

$$h \leq \frac{75}{f[GHz]\sqrt{\varepsilon_r - 1}},\ \text{mm} \qquad (16)$$

3. NUMERICAL RESULTS

The above approach is applied to the microstrip antenna arrays with number of elements from 2 to 4096 ($1 \leq n \leq 12$) and element spacing d = 0.5λ_0, 0.6 λ_0, 0.7 λ_0 and 0.8 λ_0 in K_u-band (10.5 < f < 13.5 GHz) for some of the most widely used high frequency circuit materials (Table 2) [5].

RT/duroid 6002 with standard copper thickness t = 17.5 μm and substrate thickness h = 0.254 mm, frequency-dependent characteristic impedance $Z_0(f)$ = 50 Ω at frequency f_0 = 11.538 GHz (λ_0 = 26 mm) and element spacing d = 0.6 λ_0 are chosen

as a basic model in the investigation. The values of standard substrate thickness are h = 0.127 mm, 0.254 mm, 0.508 mm and 0.762 mm.

Table 2. Properies of high frequency circuit materials produced by Rogers Corporation (at 10 GHz)

Property / Product	Composition	Relative dielectric constant ε_r	Dissipation factor tanδ	Standard copper thickness µm	Standard substrate thickness, mm
RT/duroid 5880	PTFE Glass Fiber	2.20	0.0009	9	0.127 0.508 3.175 0.254 0.787 0.381 1.575
RT/duroid 6002	PTFE Ceramic	2.94	0.0012	17.5	0.127 0.508 1.524 0.254 0.762 3.048
RT/duroid 6006	PTFE Ceramic	6.15	0.0019	35	0.254 1.270 2.540 0.635 1.905
RT/duroid 6010LM	PTFE Ceramic	10.20	0.0023	70	0.254 1.270 2.540 0.635 1.905

The microstrip feed line losses are calculated using the expressions in Section 2 and programme MICRO [2]. The effect of frequency, element spacing and substrate parameters on microstrip feed line losses is shown in Figures 3 – 8. It is seen from these figures that the feed line losses L increase moderately for number of elements from 100 to 1000 and considerably for values of number of elements higher than 1000. The feed line losses increase with an increase of number of elements and obtain values up to 5 dB for N = 4096 (Fig.7).

Figure 3 shows that the effect of frequency in K_u-band on the feed line losses is negligible. For instance the feed line losses increase only with 0.2 dB when the frequency ranges from 10.5 GHz to 13.5 GHz for N = 1024 and with 0.4 dB for N = 4096.

The effect of element spacing d on the feed line losses is shown in Figure 4. The typical values for element spacing between 0.5 λ_0 and 0.8 λ_0 are chosen in this study: when d < 0.5 λ_0 the mutual coupling between antenna array elements increases and the values of element spacing d > 0.8 λ_0 lead to an appearance of grating lobes (in fact d should be bigger than λ_0). It is seen from Figure 4 that the increase of element spacing leads to moderate increase of feed line losses. For example the increase of feed line losses is 0.6 dB when the element spacing ranges from 0.5 λ_0 to 0.8 λ_0 for N = 1024 and 1.2 dB for N = 4096. It is very important to note that the decrease of antenna array directivity and gain in this case is bigger than these values because of

degradation of radiation pattern of the antenna array for values of element spacing near to λ_0.

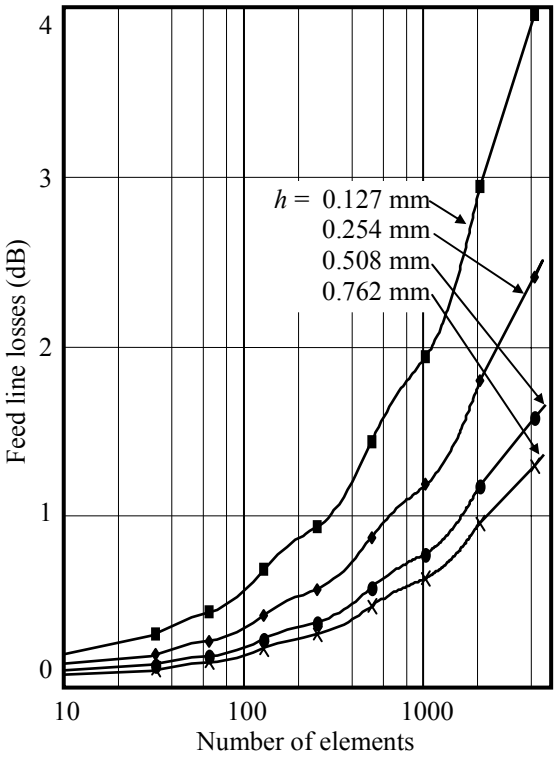

Figure. 5. Feed line losses L versus number of elements N and substrate thickness h

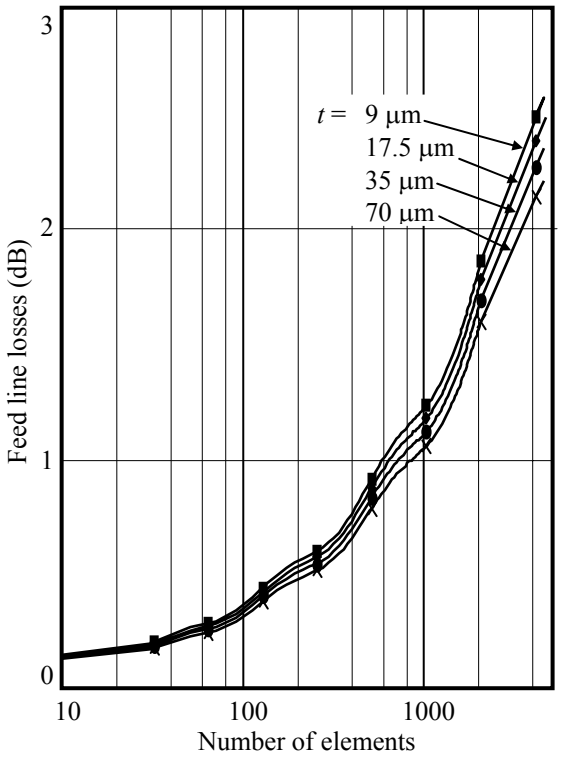

Figure. 6. Feed line losses L versus number of elements N and conductor thickness t

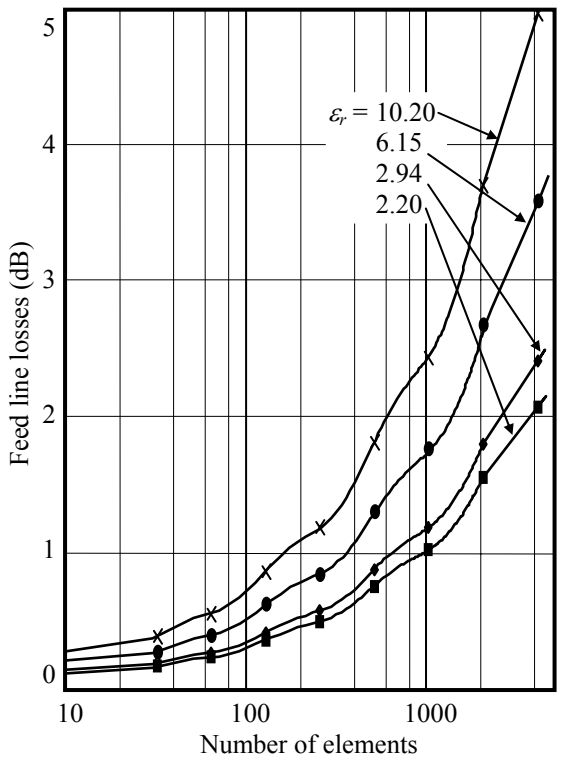

Figure. 7. Feed line losses L versus number of elements N and dielectric constant ε_r

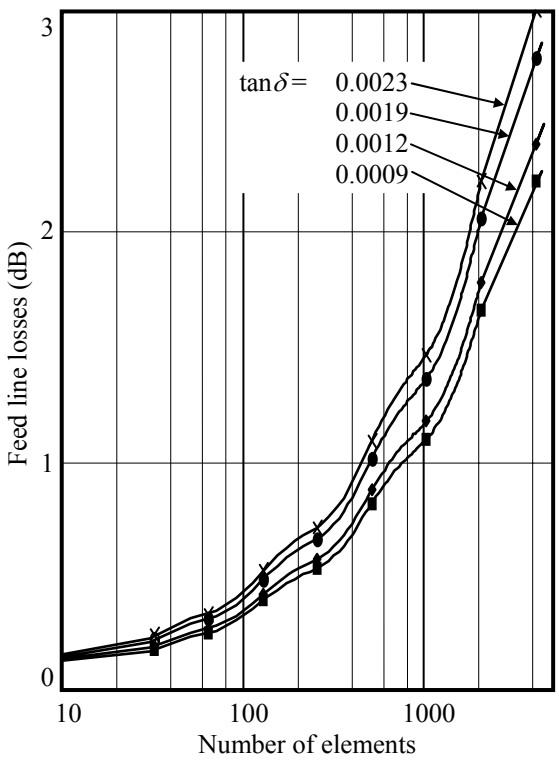

Figure. 8. Feed line losses L versus number of elements N and dissipation factor $\tan\delta$

Figure 5 shows the effect of substrate thickness h on the feed line losses. It is seen that the decrease of substrate thickness from 0.762 mm to 0.127 mm leads to an increase of feed line losses of 1.3 dB for $N = 1024$ and 2.6 dB for $N = 4096$. In reality the differences of 1.3 dB and 2.6 dB are smaller because the last two values $h = 0.508$ mm and $h = 0.762$ mm don't satisfy the requirements of (15) and thereby their radiation increases the feed line losses.

The effect of conductor thickness t on the feed line losses shown in Figure 6 is negligible. For instance the increase of conductor thichness from 9 μm to 70 μm decreases the feed line losses with 0.18 dB for $N = 1024$ and with 0.36 dB for $N = 4096$ but the accuracy of practical feed line implementation also decreases [6,7].

The four previous steps in this investigation (a study of the effect of frequency, element spacing, substrate and conductor thickness on the feed line losses) were based on a real substrate material (RT/duroid 6002). The effect of the dielectric constant and dissipation factor tanδ on the feed line losses is carried out using an imaginable substrate material but with parameters (ε_r and tanδ) of the four already used in the investigation high frequency circuit materials cited in Table 2.

The effect of the relative dielectric constant ε_r on the feed line losses is shown in Figure 7. An increase of 1.4 db is found for $N = 1024$ and 2.9 dB for $N = 4096$ when ε_r ranges from 2.20 to 10.20. In fact the courves for $\varepsilon_r = 2.20$ and 2.94 in the Figure 7 should be raised because of increased radiation of the feed line - these two cases don't satisfy the condition (15).

Figure 8 shows the effect of the dissipation factor tanδ on the feed line losses. An increase of 0.37 dB is found for $N = 1024$ and 0.76 dB for $N = 4096$ when the tanδ ranges from 0.0009 to 0.0023.

4. CONCLUSION

The study carried out here allows to be formulated the following conclusions:

- The behaviour of courves in Figure 3 (an effect of frequency) and Figure 6 (an effect of conductor thickness) is similar because of the same influence of these two parameters on the nature of physical processes in the microstrip lines and antennas (in particular an appearance of the skin effect).
- The decrease of the substrate thickness (Figure 5) and increase of dielectric constant (Figure 7) influence in the same way on the propagation of the

electromagnetic waves along the microstrip feed line. Because of this reason the behaviour of courves in Figure 5 and Figure 7 is similar.

- The results obtained in this study may be used in the design of microstrip antenna arrays with various feed techniques such as microstrip line, proximity-coupled and aperture-coupled feed.
- In the case when the feed network includes different passive components such as phase shifters, attenuators etc, one should take into account the losses due to their presence.

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